

# Central Appalachian Basin Unconventional (Coal/Organic Shale) Reservoir Small-Scale CO<sub>2</sub> Injection Test

Project Number: DE-FE0006827

***Nino Ripepi***

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Virginia Center for Coal and Energy Research at  
Virginia Tech

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U.S. Department of Energy  
National Energy Technology Laboratory  
Carbon Storage R&D Project Review Meeting  
Developing the Technologies and Building the  
Infrastructure for CO<sub>2</sub> Storage  
August 21-23, 2012

# Presentation Outline

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- Benefit to the Program
- Goals and Objectives
- Organization
- Technical Overview
  - Characterization
  - Site Selection
  - Modeling
  - MVA Plans
- Schedule

# Project Overview: Goals and Objectives

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## ★ Objectives:

- Inject up to 20,000 metric tons of CO<sub>2</sub> into **3 vertical CBM wells** over a one-year period in Central Appalachia
- Perform a small (approximately 300-1000 metric tons) Huff and Puff test in a **horizontal shale gas well**

★ **Duration:** 4 years, October 1, 2011–September 30, 2015

## ★ Goals

- Test the storage potential of unmineable coal seams and shale reservoirs
- Learn about adsorption and swelling behaviors of coal and shale (methane vs. CO<sub>2</sub>)
- Test the potential for enhanced coalbed methane (ECBM) and enhanced gas (EGR) production and recovery
- Improve knowledge of unconventional and stacked storage systems (coal and shale)

# Research Partners

- Virginia Center for Coal and Energy Research (Virginia Tech)
- Cardno Marshall Miller & Associates
- Gerald Hill
- Southern States Energy Board
- Virginia Department of Mines, Minerals and Energy
- Geological Survey of Alabama
- Sandia Technologies
- Det Norske Veritas (DNV)
- Consol Energy (Research Group)

## Industrial Partners

- **Consol Energy (CNX Gas)**
- Harrison-Wyatt, LLC
- Emory River, LLC
- Dominion Energy
- Alpha Natural Resources

## Collaborators

- Schlumberger
- Global Geophysical
- Oak Ridge National Laboratory

# Project Timeline

## Phase I

18 months  
(10/1/11 – 3/31/13)

- Characterization
  - Well Logs
  - Thickness, structure, production
  - Core sample analysis
  - Modeling
- Injection design
- Monitoring design
  - Well locations
  - Geophysical surveys
- **Go/no go 1: permits, access (12 months)**
- **Go/no go 2: characterization (18 months)**

## Phase II

18 months  
(4/1/13 – 9/30/14)

- Site preparation
  - Conversion of production wells
  - Drill monitor wells
  - Install additional monitor stations
- **CO<sub>2</sub> injection (12/01/2013-11/30/2014)**
- Monitoring
  - Atmosphere
  - Surface
  - Reservoir

## Phase III

12 months  
(10/1/14 – 9/30/15)

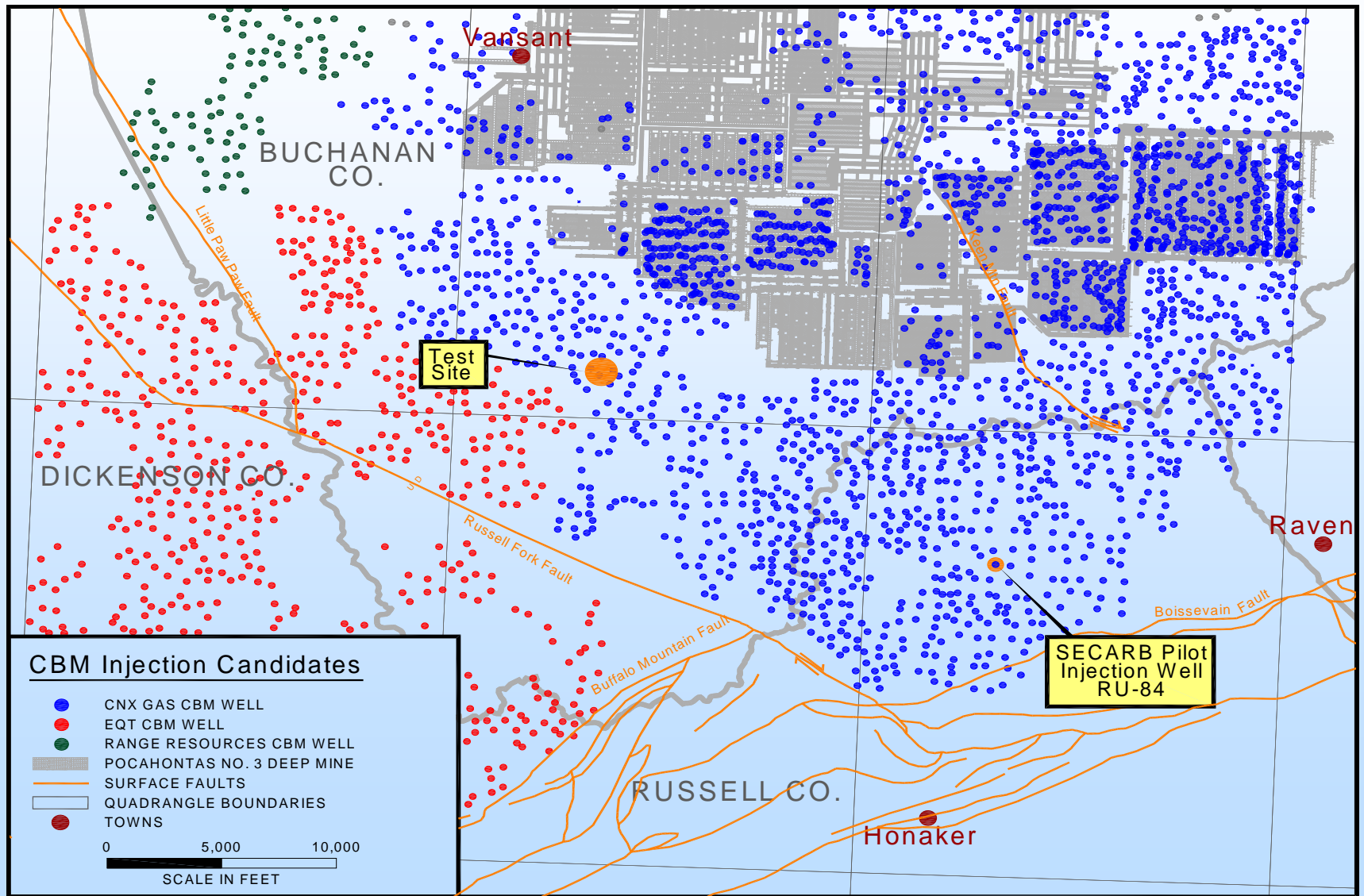
- Site closure
  - Conversion of injection and monitor wells
  - Site restoration
- Post-injection characterization
  - Data analysis and interpretation
  - Post-injection monitoring
  - Reservoir modeling

Ongoing: Management and Planning, Risk Analysis and Assessment, Characterization, Modeling, Monitoring, Education/Outreach

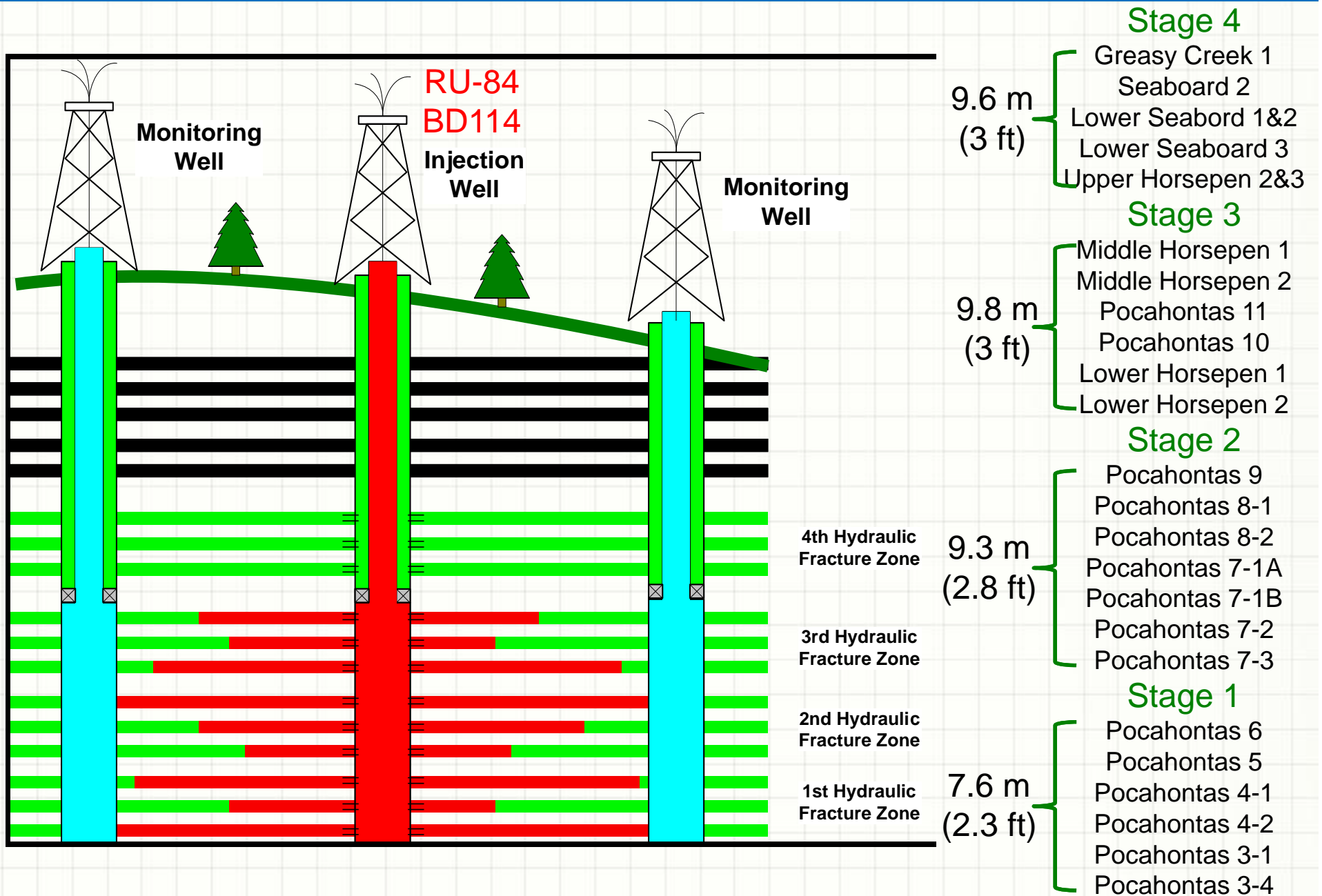
# CBM Test – Selection Criteria

- CONSOL Operation
  - Mineral and Surface Ownership
  - Access
  - Production
  - EUR
  - Depletion
  - Depth
  - Structure
  - Continuity
  - Regional Seals
  - Faulting
  - In-Fill Wells
  - Perforations, Stimulation and Breakdown (Frac Records)
- 
- The diagram consists of two yellow boxes with blue borders. The first box, labeled 'Decline Curve Analysis', is connected by a bracket to the criteria: Production, EUR, Depletion, and Depth. The second box, labeled 'Cross-Sections / Seismic Interpretation', is connected by a bracket to the criteria: Structure, Continuity, Regional Seals, and Faulting.
- Decline Curve Analysis
- Cross-Sections / Seismic Interpretation

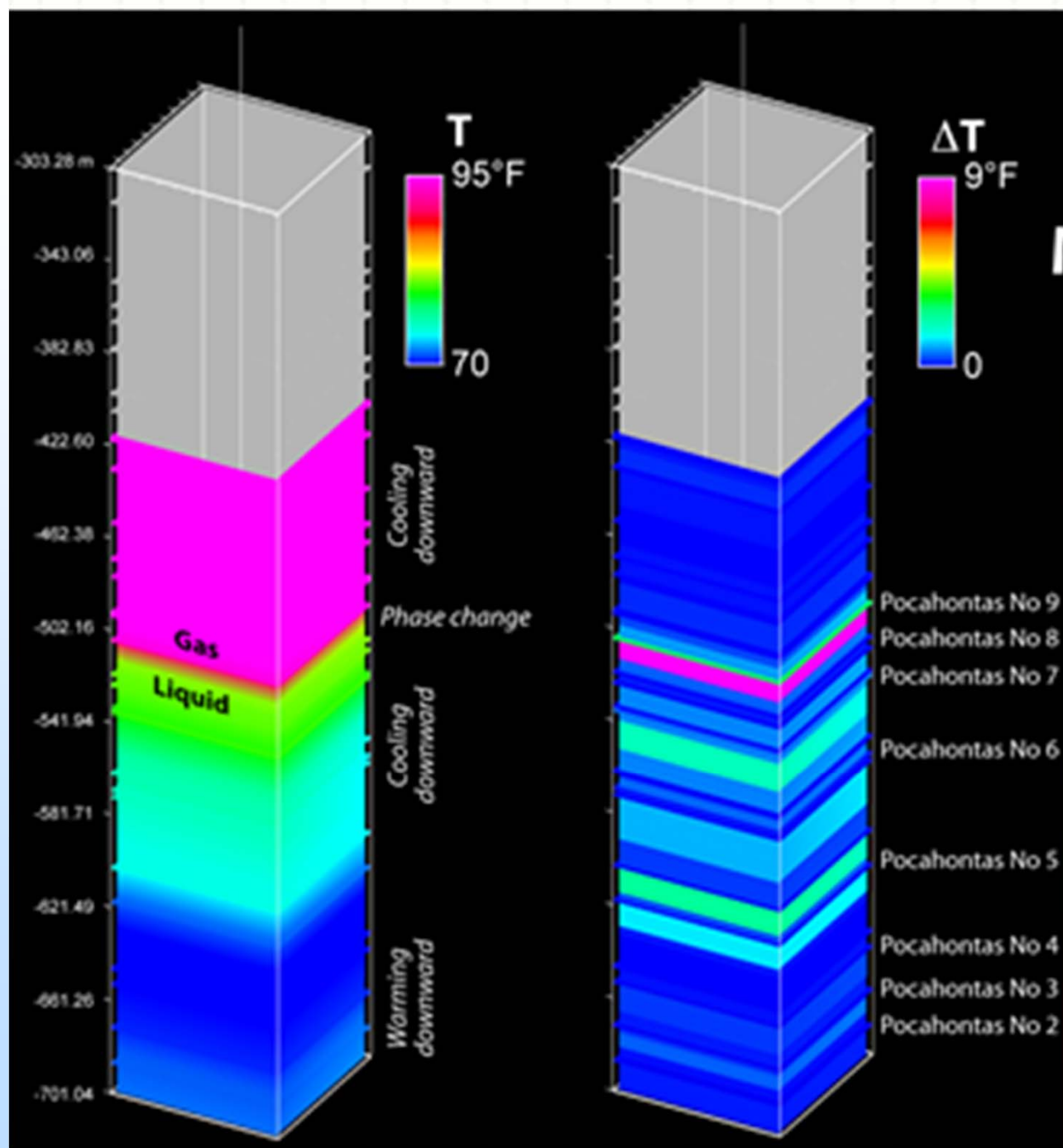
# CBM Injection Test Sites Russell and Buchanan Counties, VA



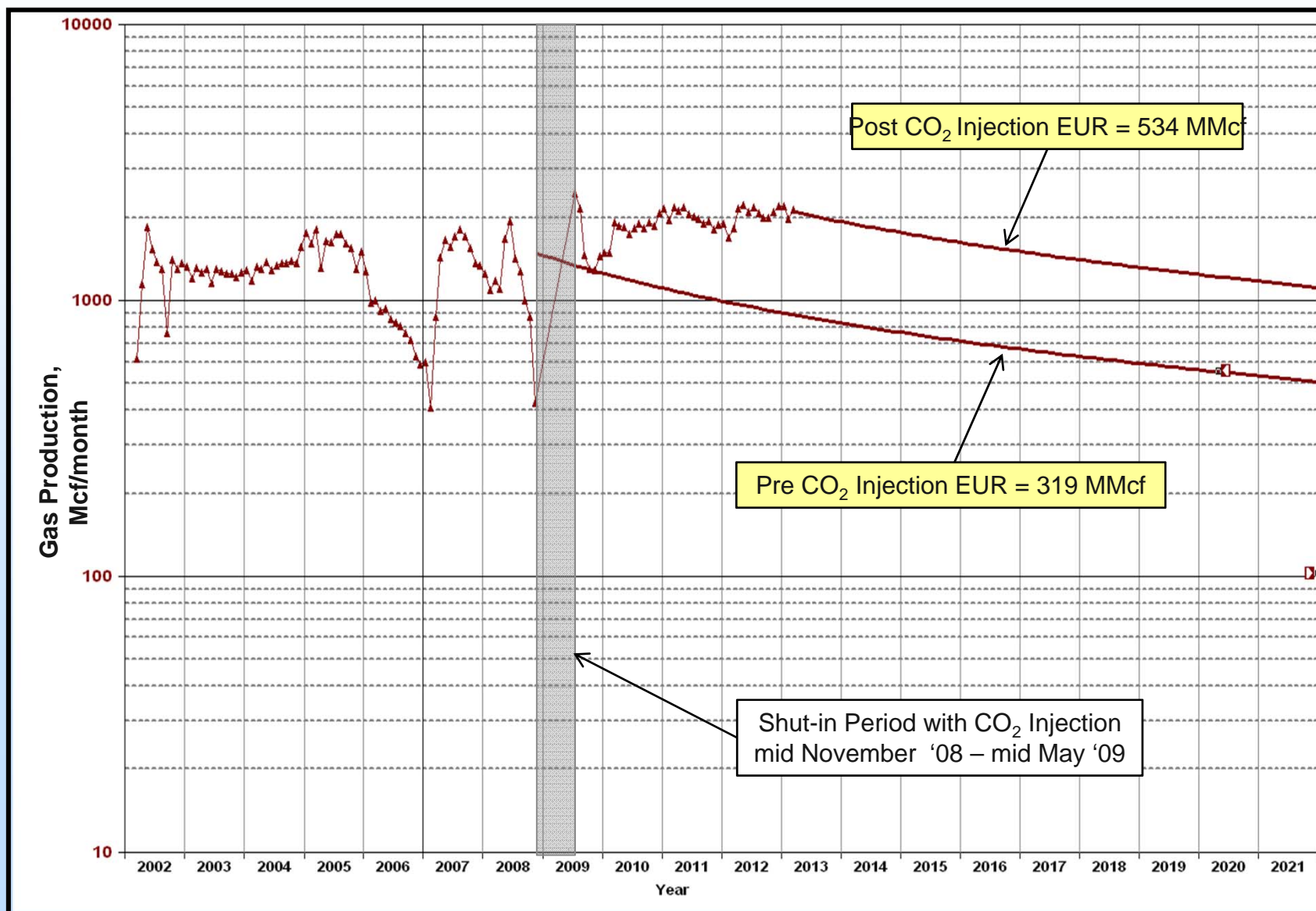
# Russell County - Coal Seams



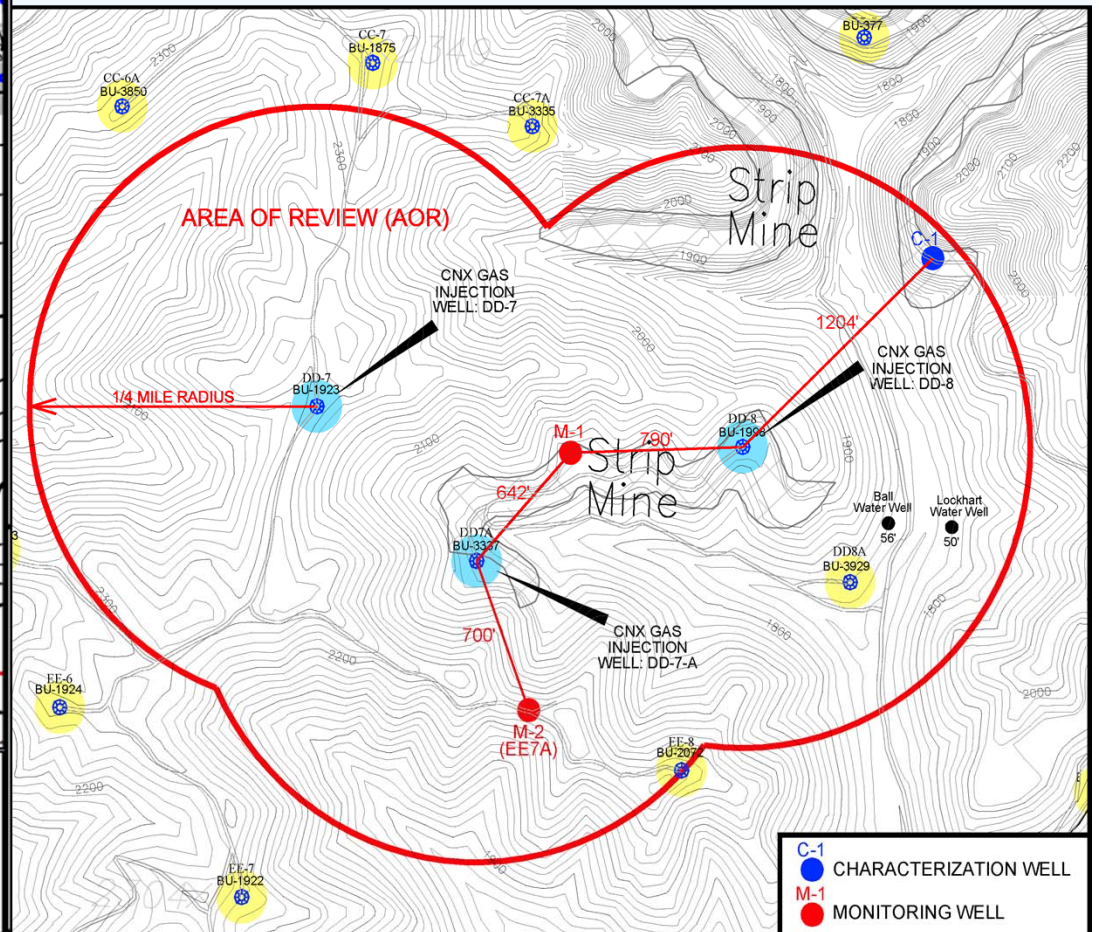
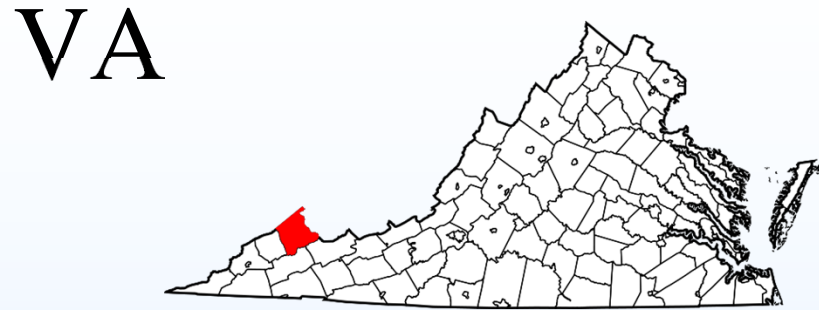
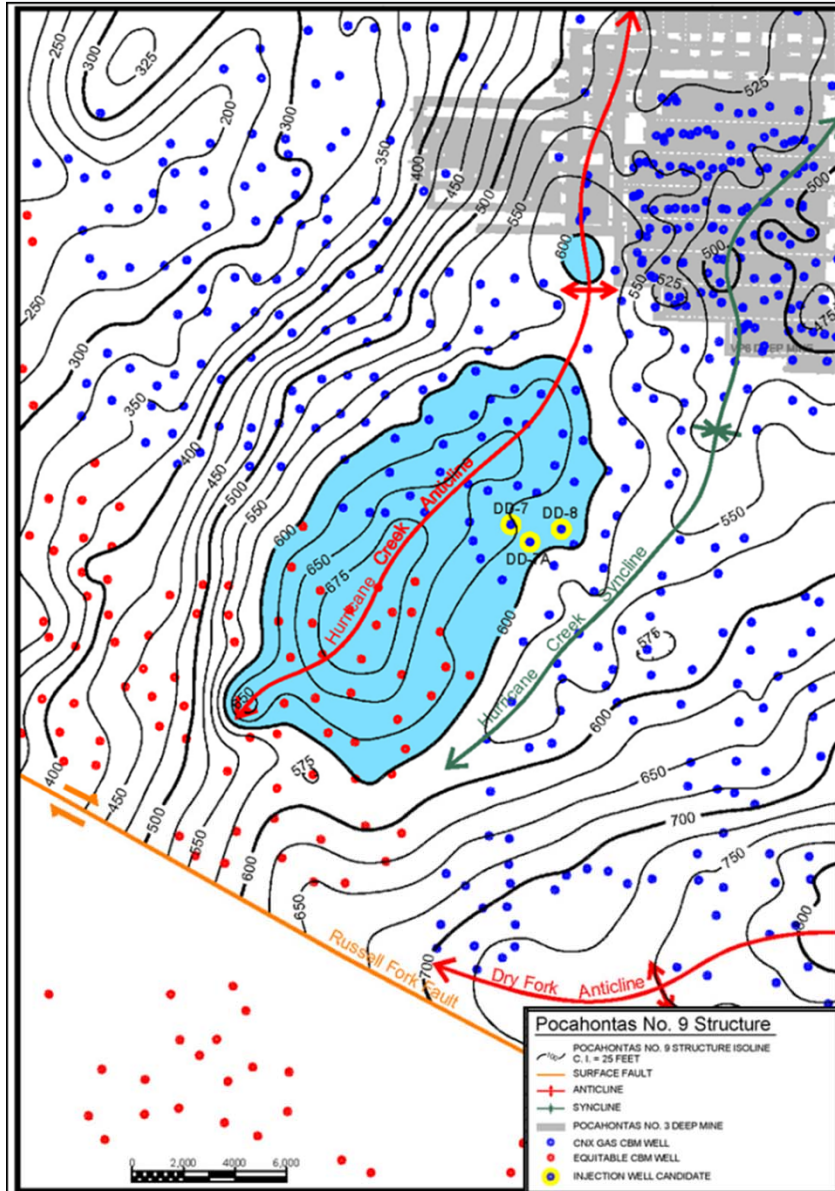




# CO<sub>2</sub> Injection Decline-Curve Analysis Phase II Injection Well RU-84 (BD-114)



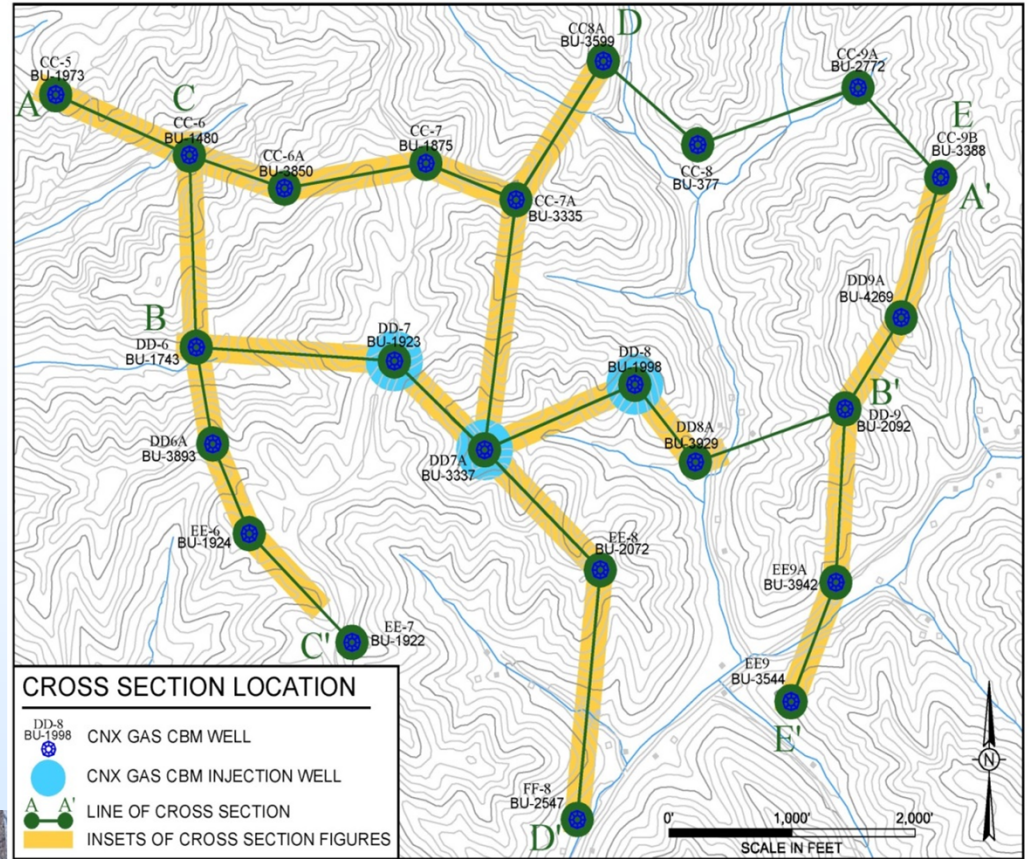
# Field demonstration in Buchanan County, VA

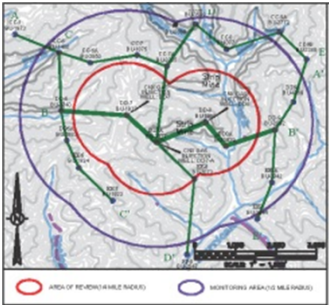


# DD8

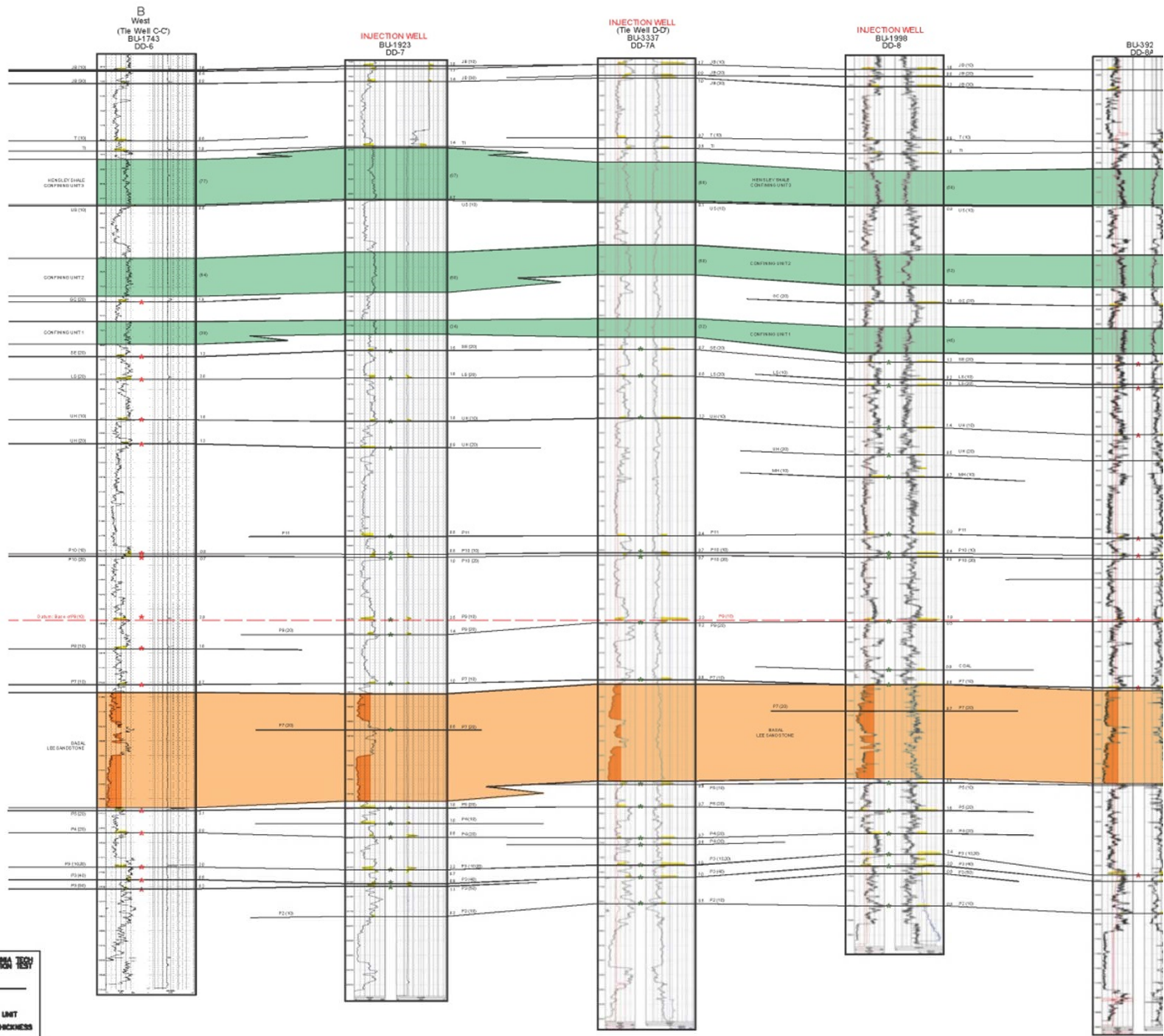


# Cross-Sections by Coal Seam





# B-B'



**EXHIBIT 2** SMALL SCALE CO<sub>2</sub> INJECTION TEST

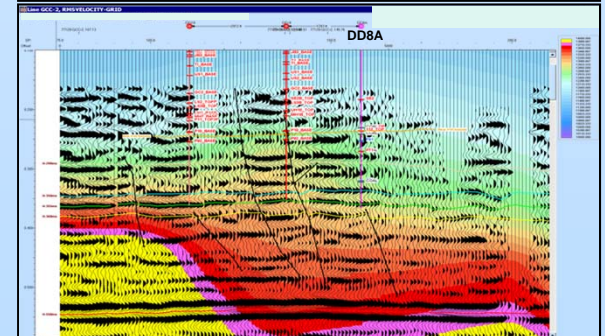
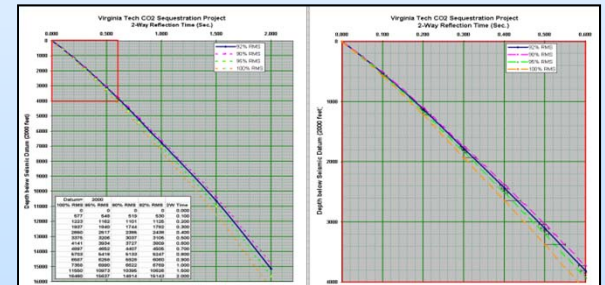
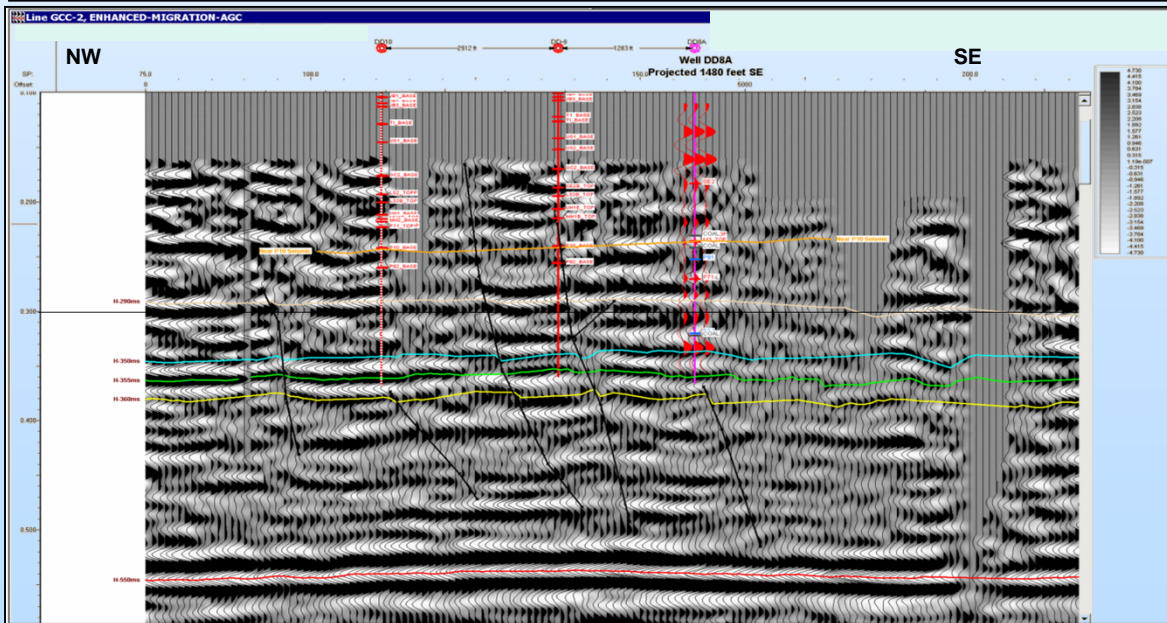
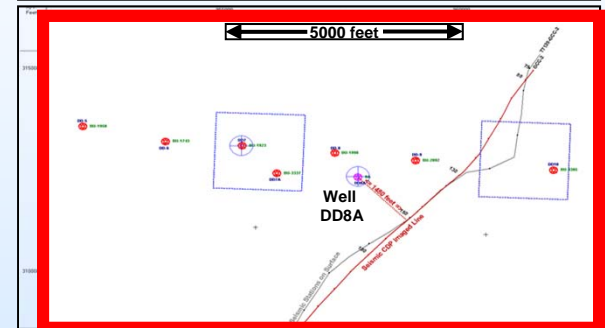
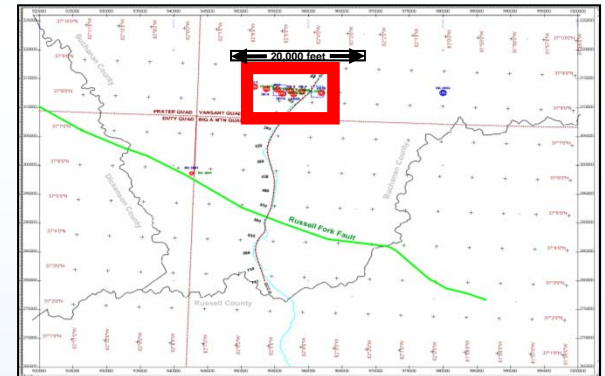
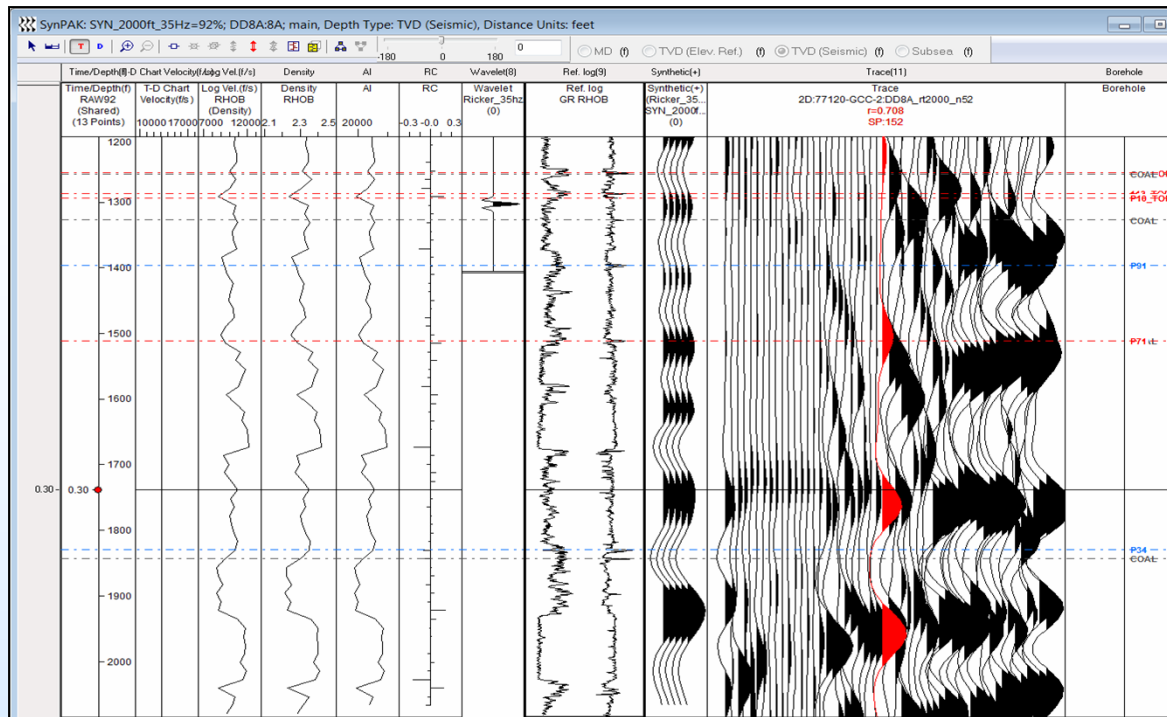
Injection Well Cross Section B - B'

VERTICAL SCALE: 1" = 50'  
HORIZONTAL SCALE: NOT TO SCALE  
DATUM: BASE OF PG (10)

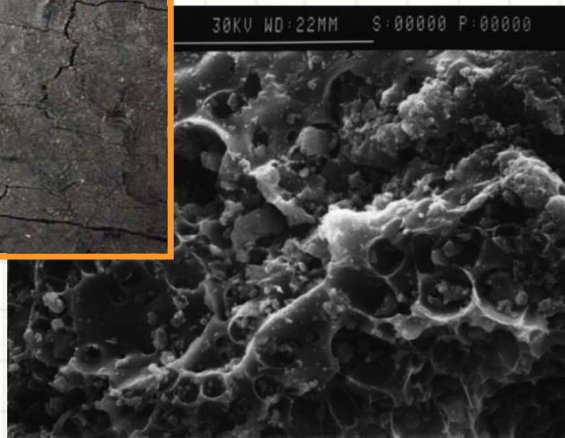
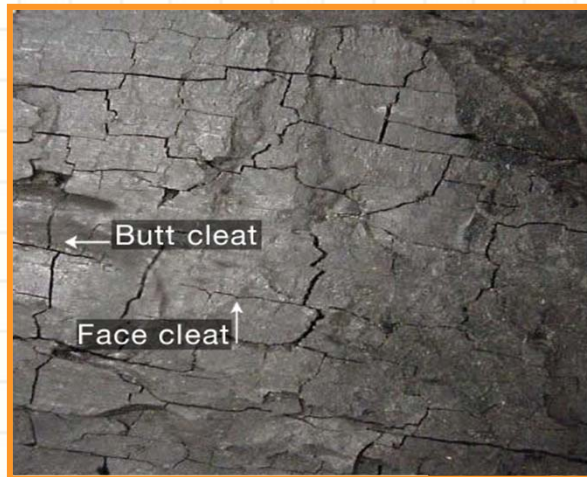
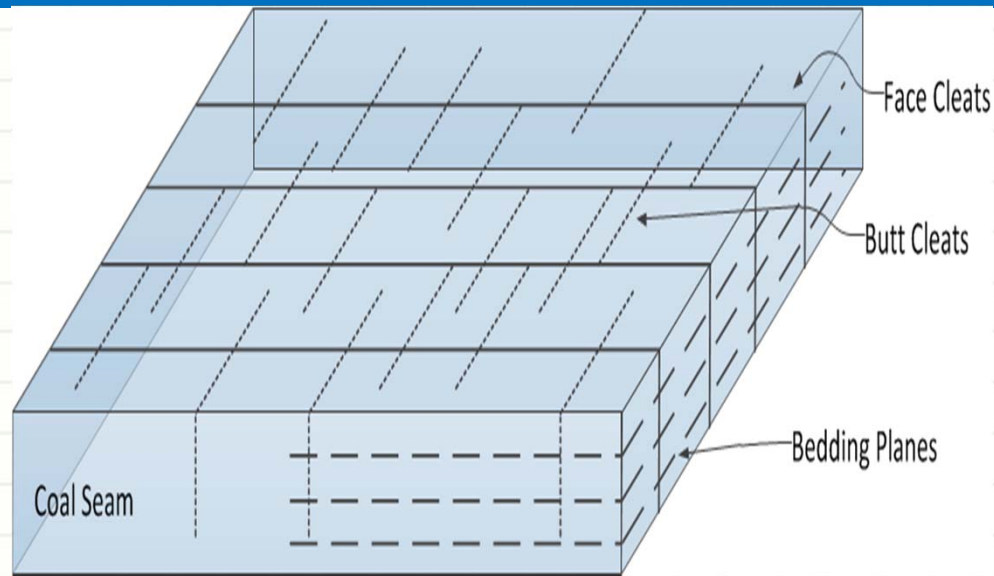
★ COMPLETED COAL SEAM  
\* INJECTION ZONE

QUARTZARENITE  
SHALE CONFINING UNIT  
CONFINING UNIT THICKNESS (FEET)

# Virginia Tech CO<sub>2</sub> Sequestration Project Well DD8A Synthetic Seismic Tie to Seismic Reflection Survey



# (E)CBM Mechanisms



## Coalbed Methane

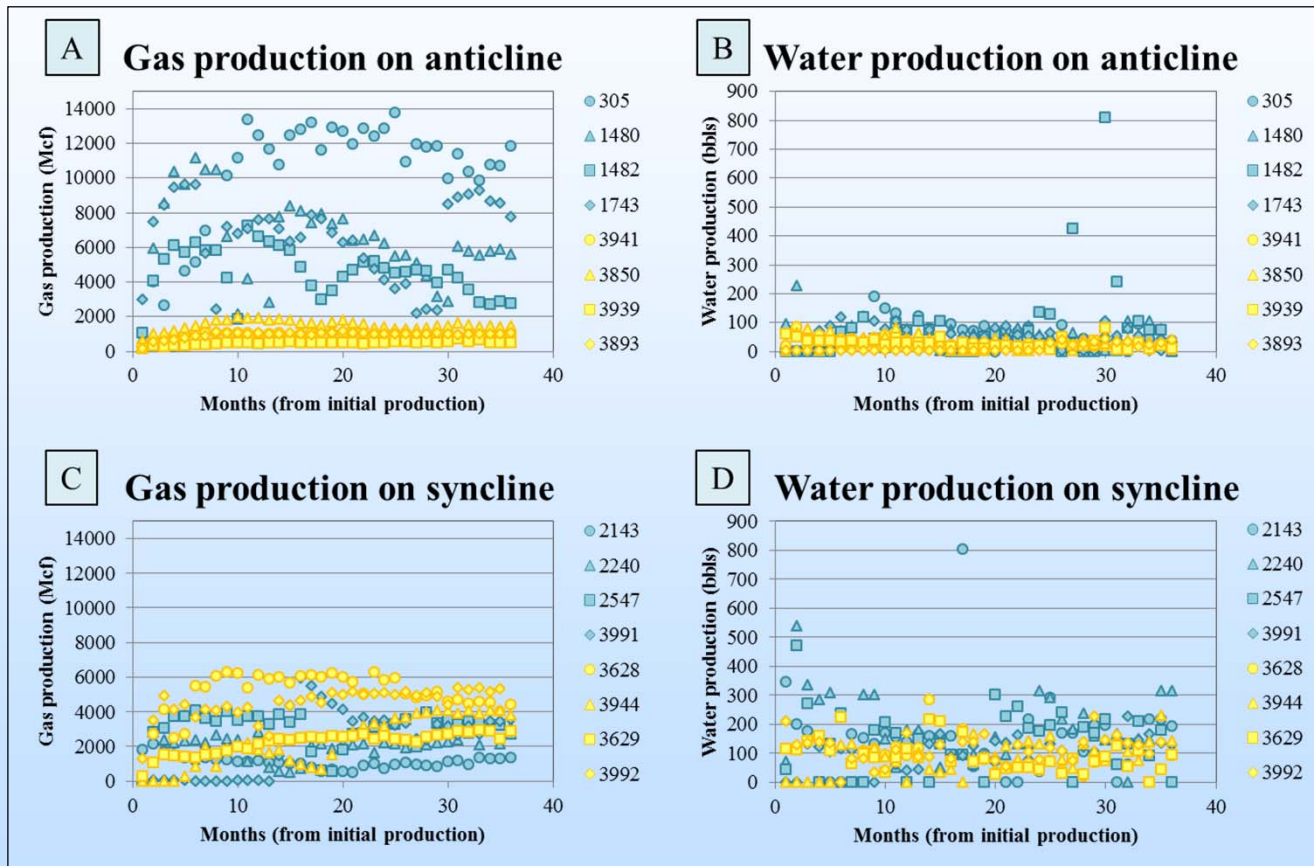
- (i) Dewatering: pressure  $\downarrow$ , effective stress  $\uparrow$ , fracture apertures  $\downarrow$  permeability  $\downarrow$
  - (ii)  $\text{CH}_4$  release  $\rightarrow$  matrix shrinkage and zero volume change condition, fracture apertures  $\uparrow$ , permeability  $\uparrow$
- Net Permeability:  
Competing effects (i)-(ii)
  - Fickian (Diffusion) and Darcy Flow

## ECBM

- (i)  $\text{CO}_2$  greater affinity to coal than  $\text{CH}_4$
- (ii) When  $\text{CO}_2$  is adsorbed matrix swells; under zero volume change condition, fracture apertures  $\downarrow$ , permeability  $\downarrow$



# CBM and water production trends vs. geologic structure

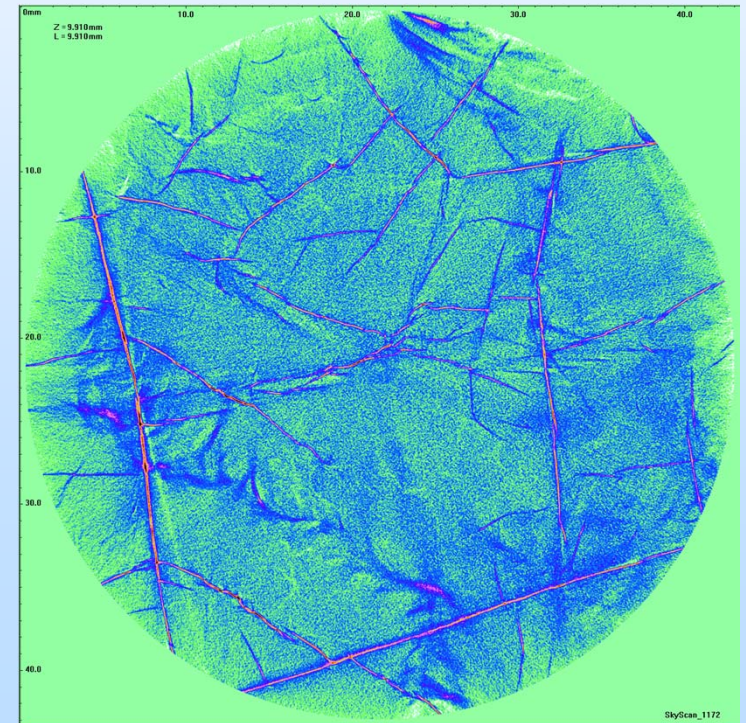
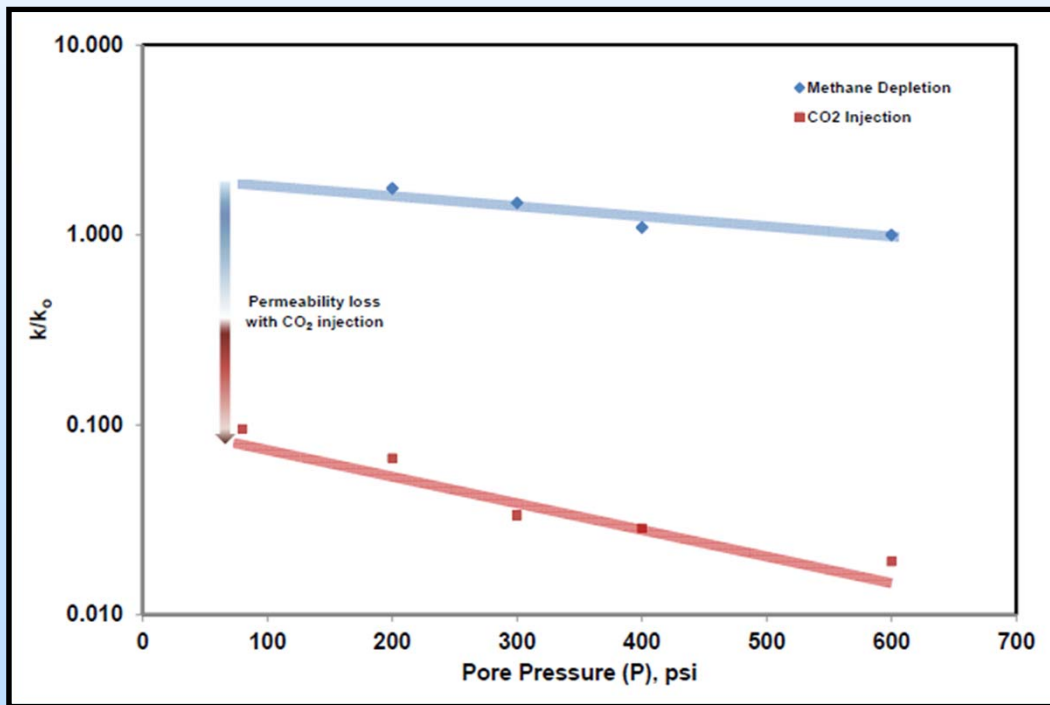
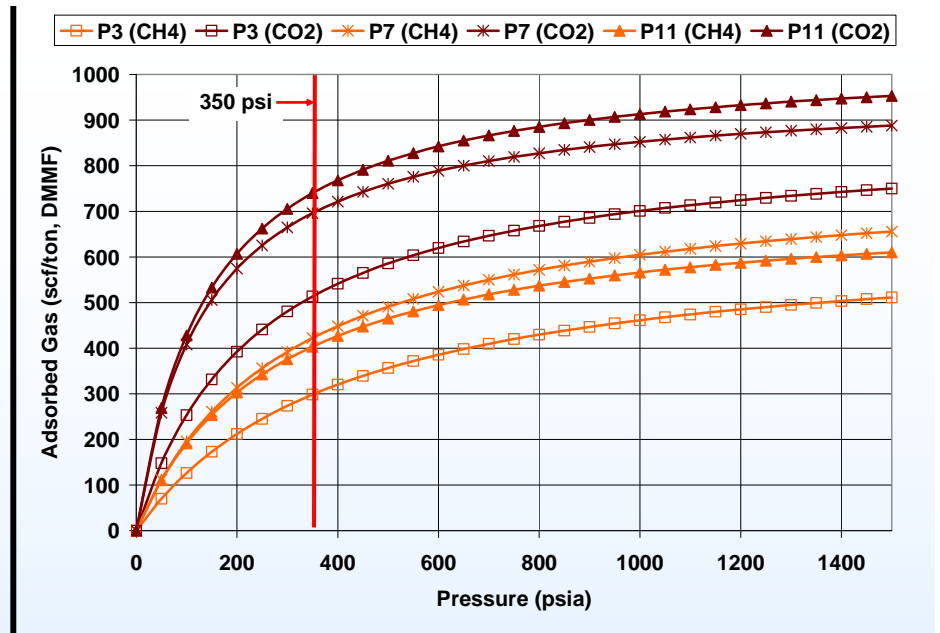


Gas and water production over 36 months for well drilled on the anticline (A, B) and for wells drilled on the syncline (C, D). Blue symbols represent initial wells and yellow symbols represent infill wells. Wells with the same symbol (circle, square, etc.) belong to the same 80-acre operational unit.

Water production higher for wells on syncline than wells on anticline.

# Modeling Issues:

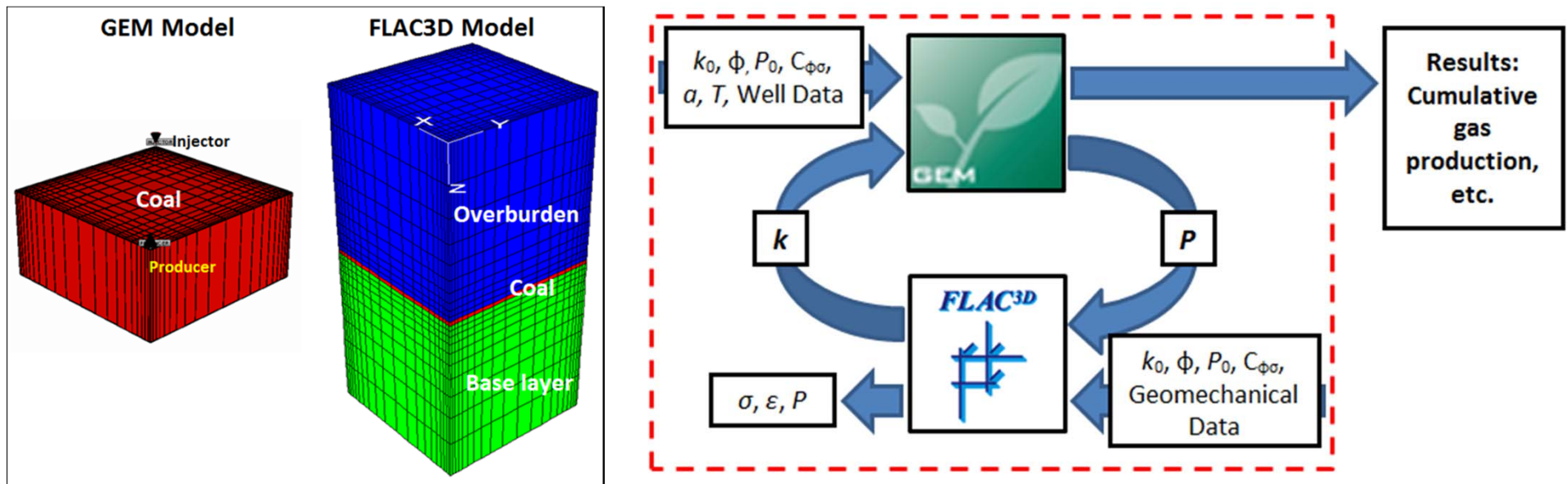
Isotherms, Gas Content, Permeability, Cleats, Fracture development are all variable by seam, depth and/or structural location



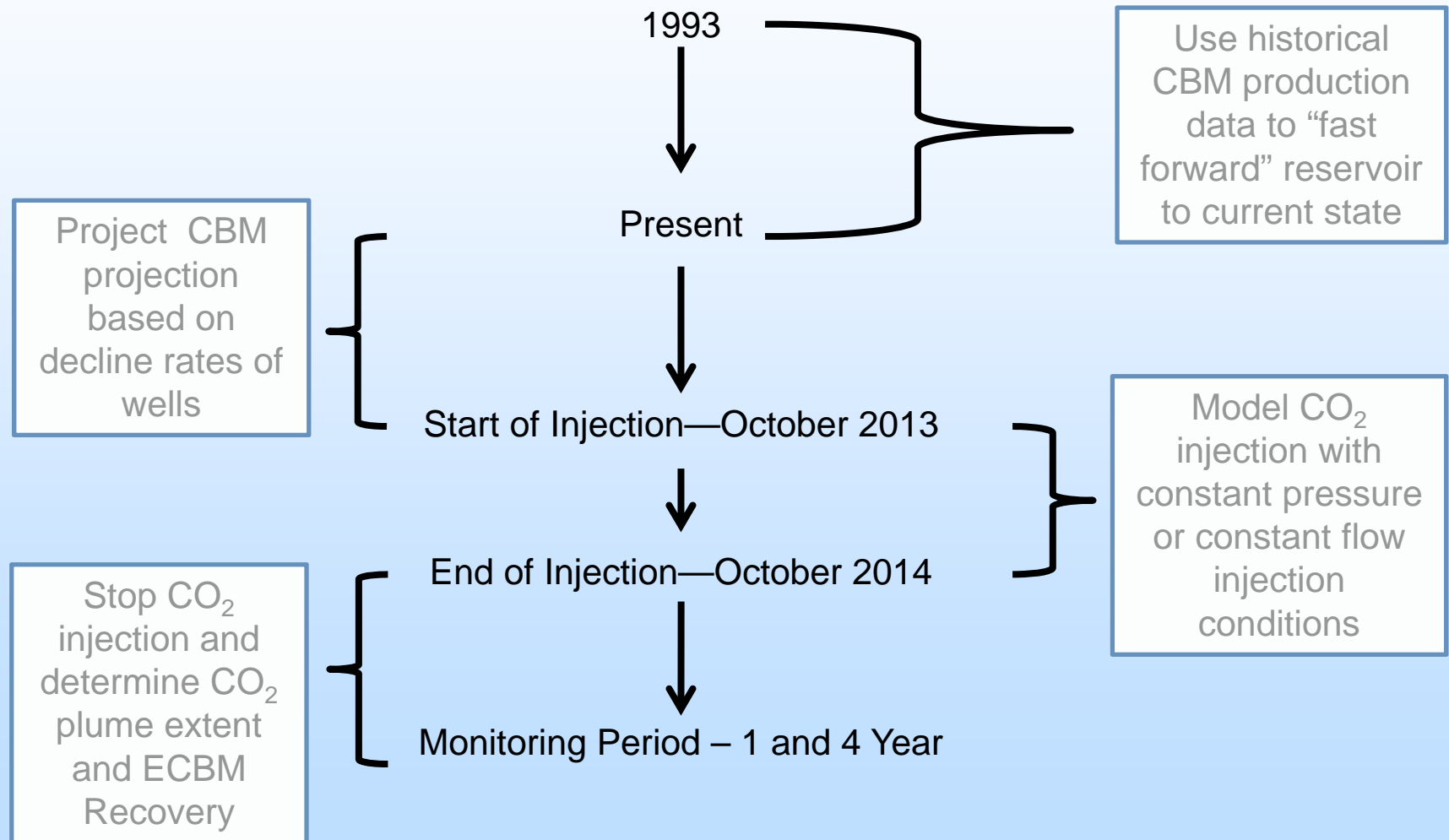
Harpalani, 2012

# Overview of Reservoir Modeling

- **Preliminary Reservoir Modeling – Single Zone**
  - ARI's COMET3
- **Detailed Reservoir Modeling**
  - Computer Modeling Group's GEM Program – By Zone (5)
  - Schlumberger's Eclipse – By Seam (15-20 seams)
- **Coupling GEM with FLAC3D for Geomechanical Modeling**

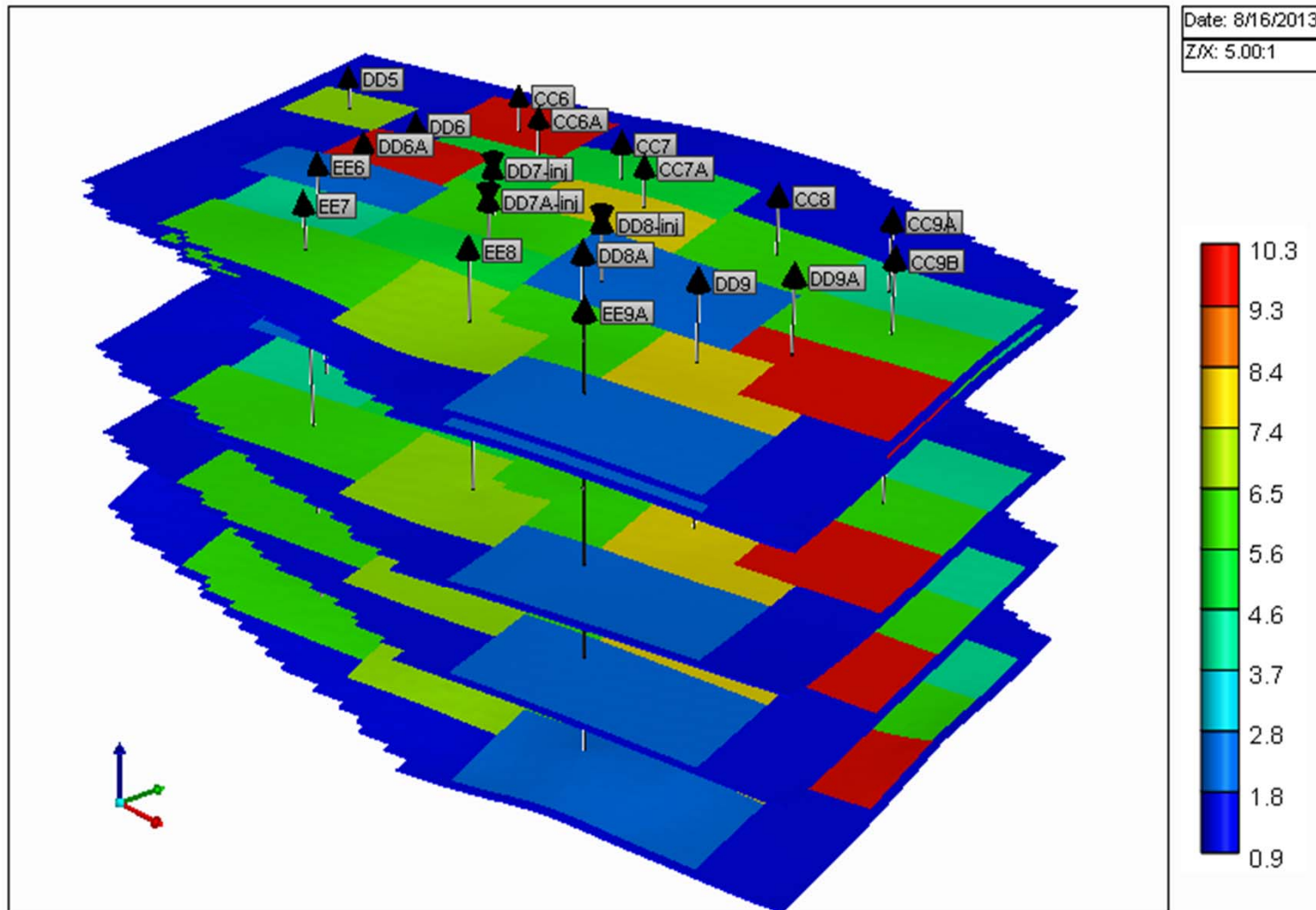


# Modeling Methodology

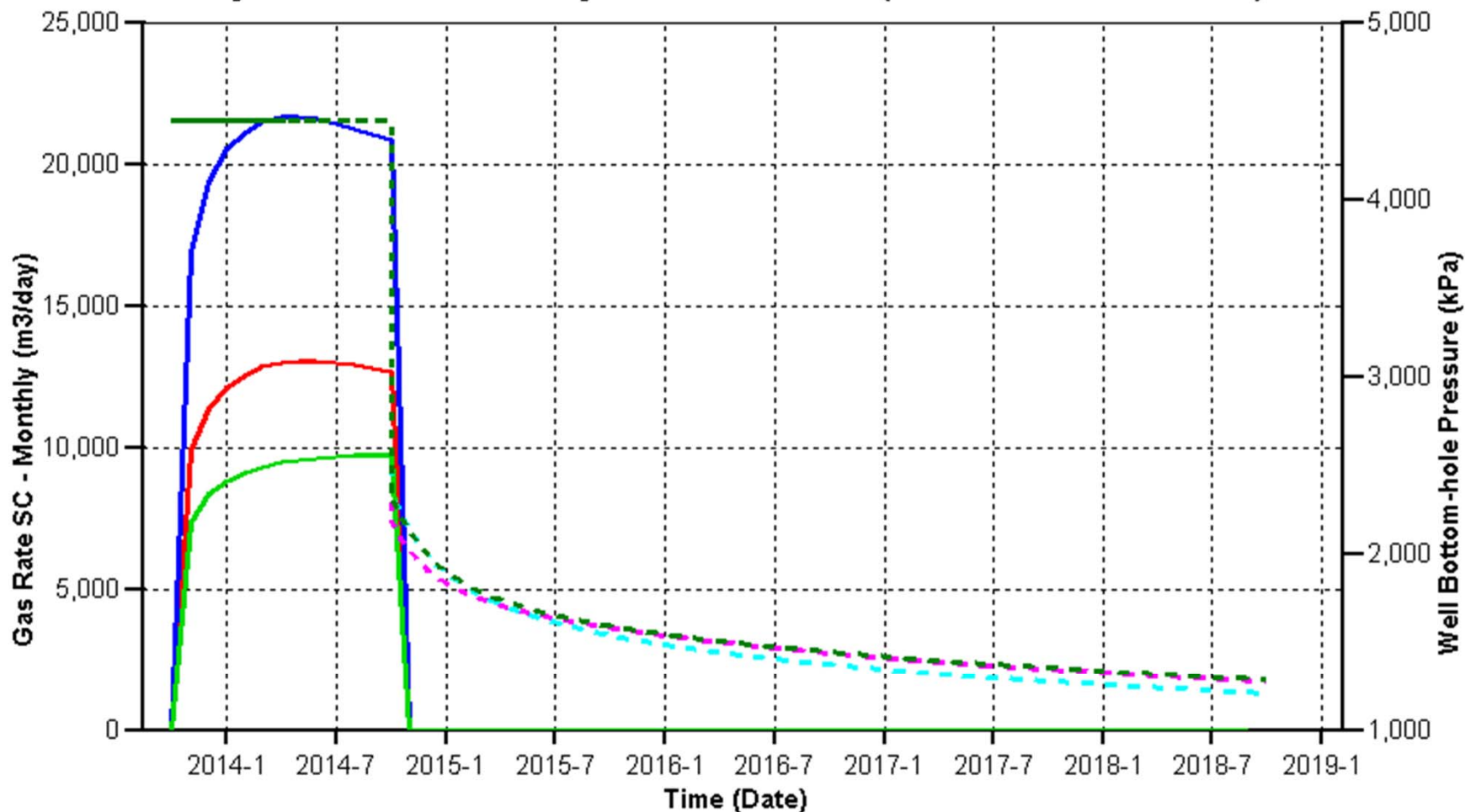


# 5 Zone – History Match of Gas and Water Production

Permeability J - Fracture (md) 2013-10-01

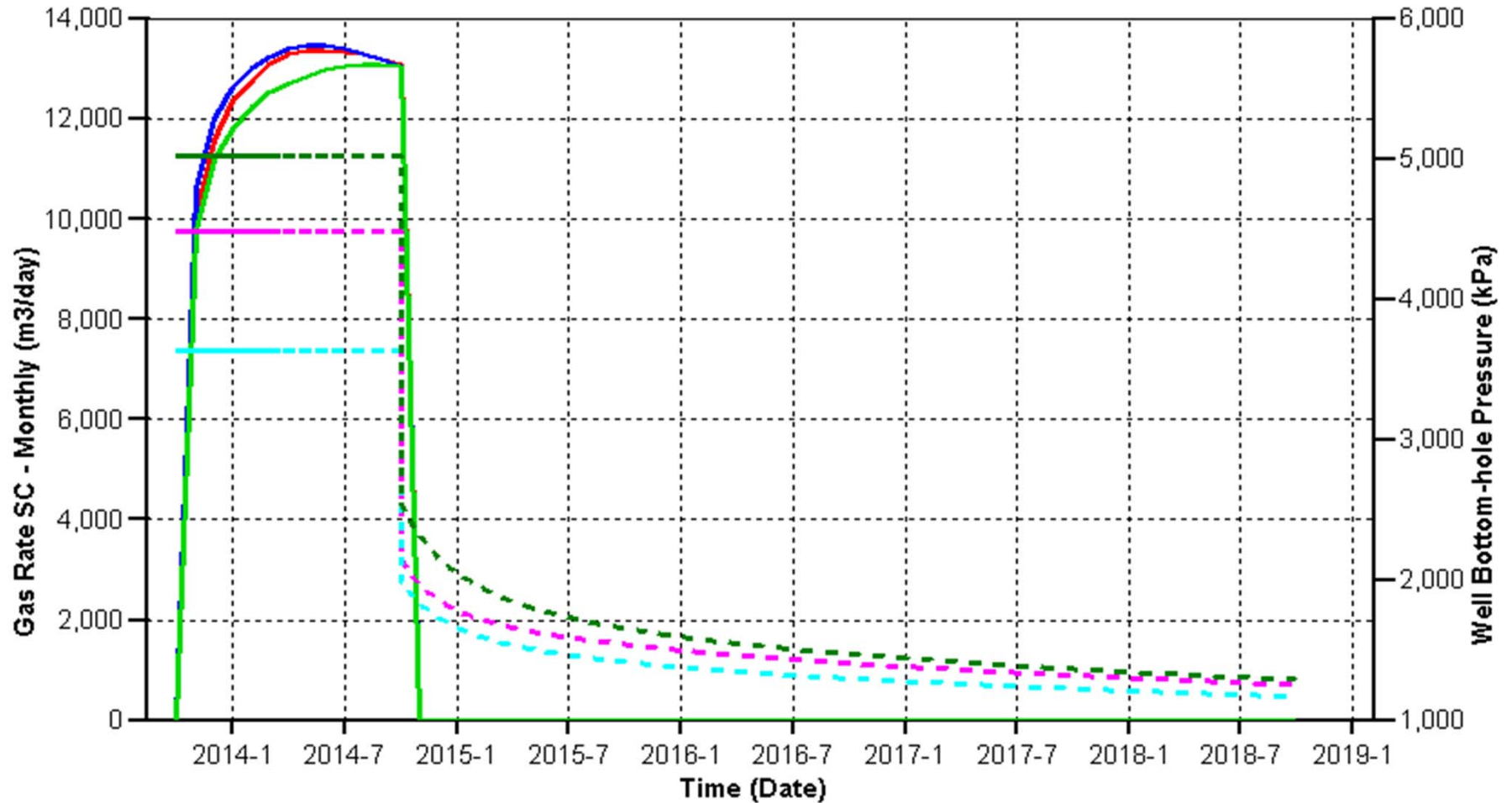


### Injection Wells - Primary Constraint=BHP (Constant for each well)



- Gas Rate-Injection (Well-DD7A)
- Gas Rate-Injection (Well-DD7)
- Gas Rate-Injection (Well-DD8)
- BHP-Injection (Well-DD7A)
- BHP-Injection (Well-DD7)
- BHP-Injection (Well-DD8)

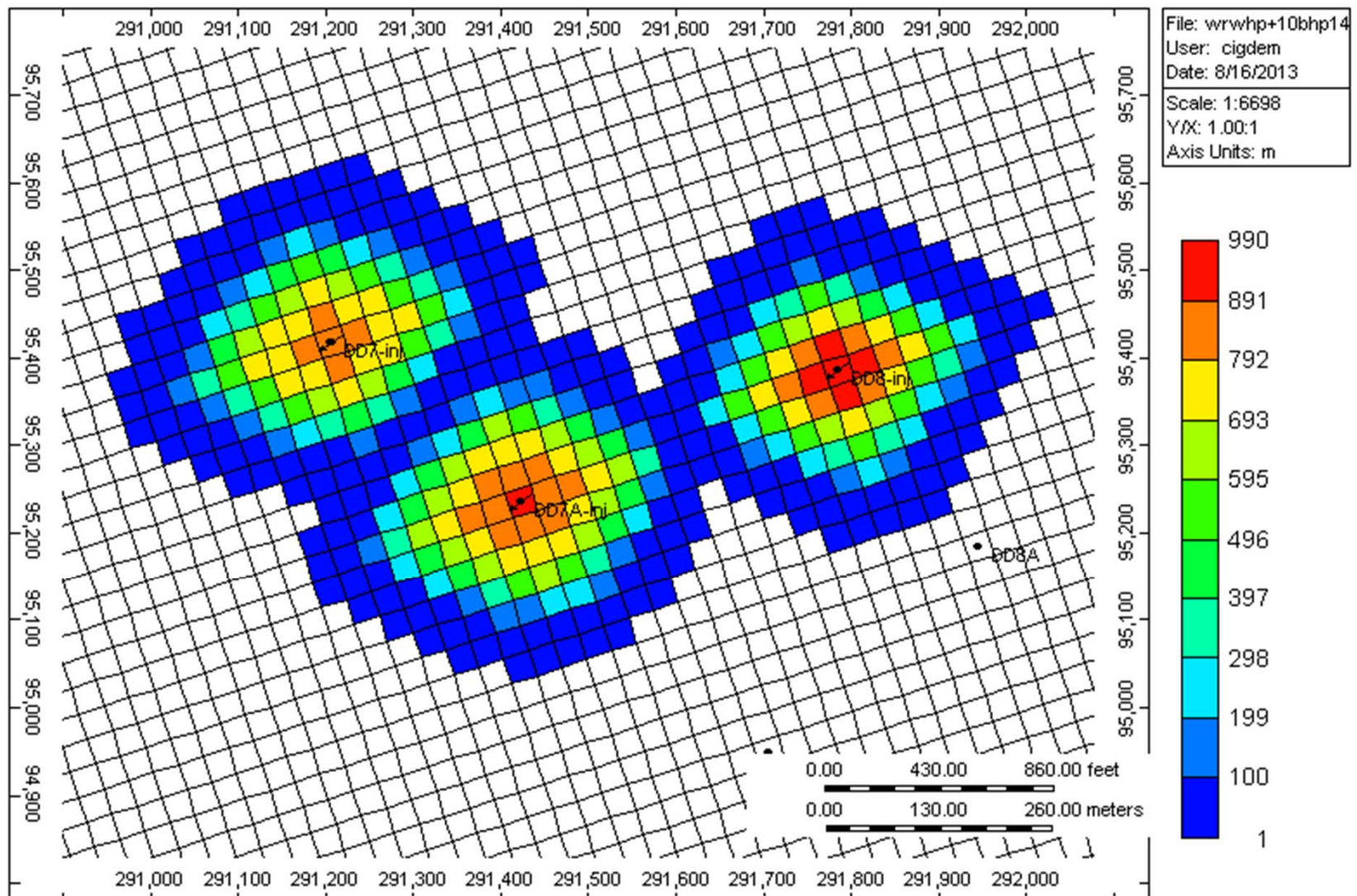
### Injection Wells - Primary Constraint=BHP (Different for each well)



- Gas Rate-Injection (Well-DD7A)
- Gas Rate-Injection (Well-DD7)
- Gas Rate-Injection (Well-DD8)
- BHP-Injection (Well-DD7A)
- BHP-Injection (Well-DD7)
- BHP-Injection (Well-DD8)

# Bottom-Hole Constraint equal in each Well

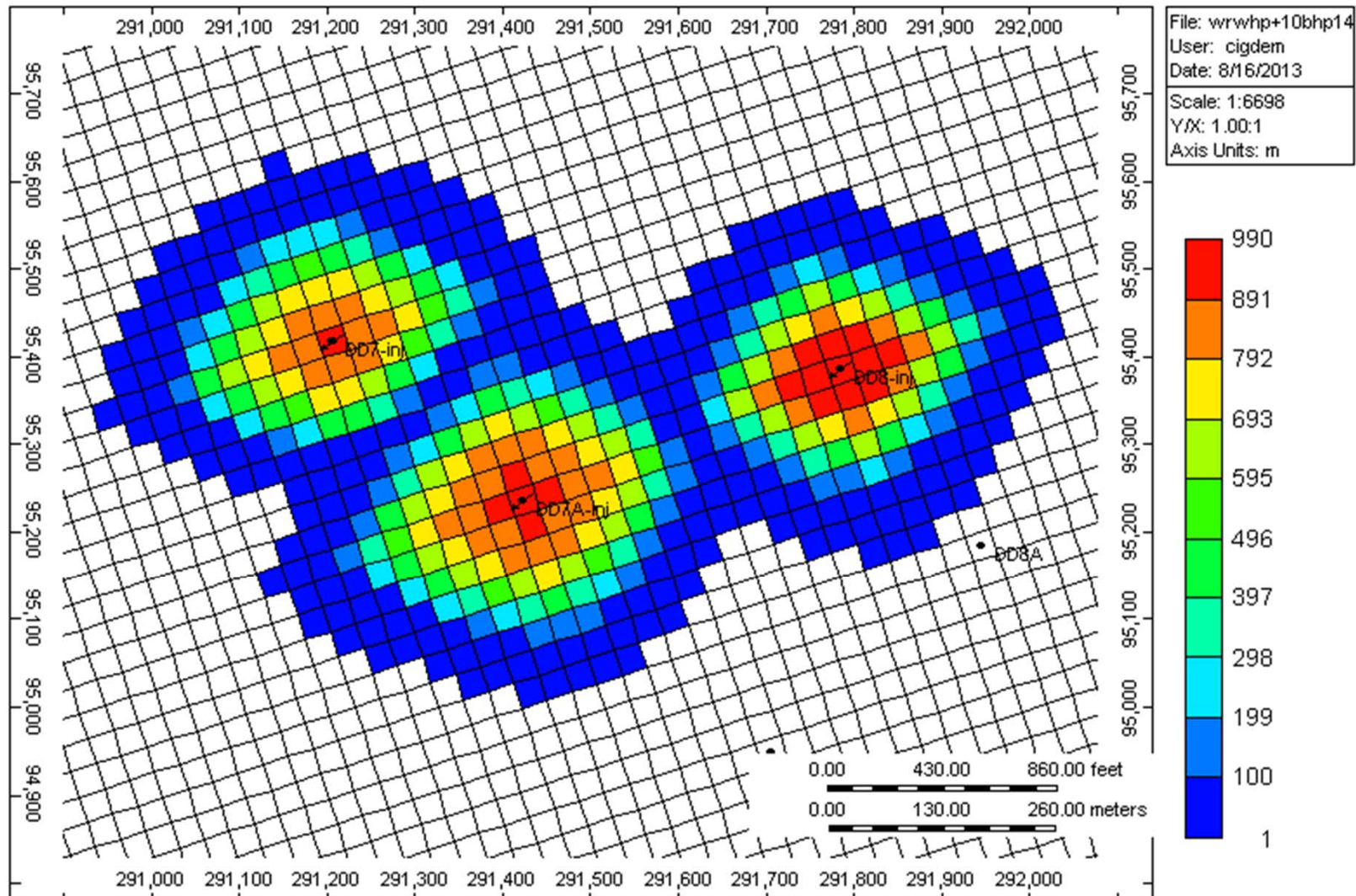
Adsorption(CO<sub>2</sub>) (gmole/m<sup>3</sup>) 2014-10-01 K layer: 2





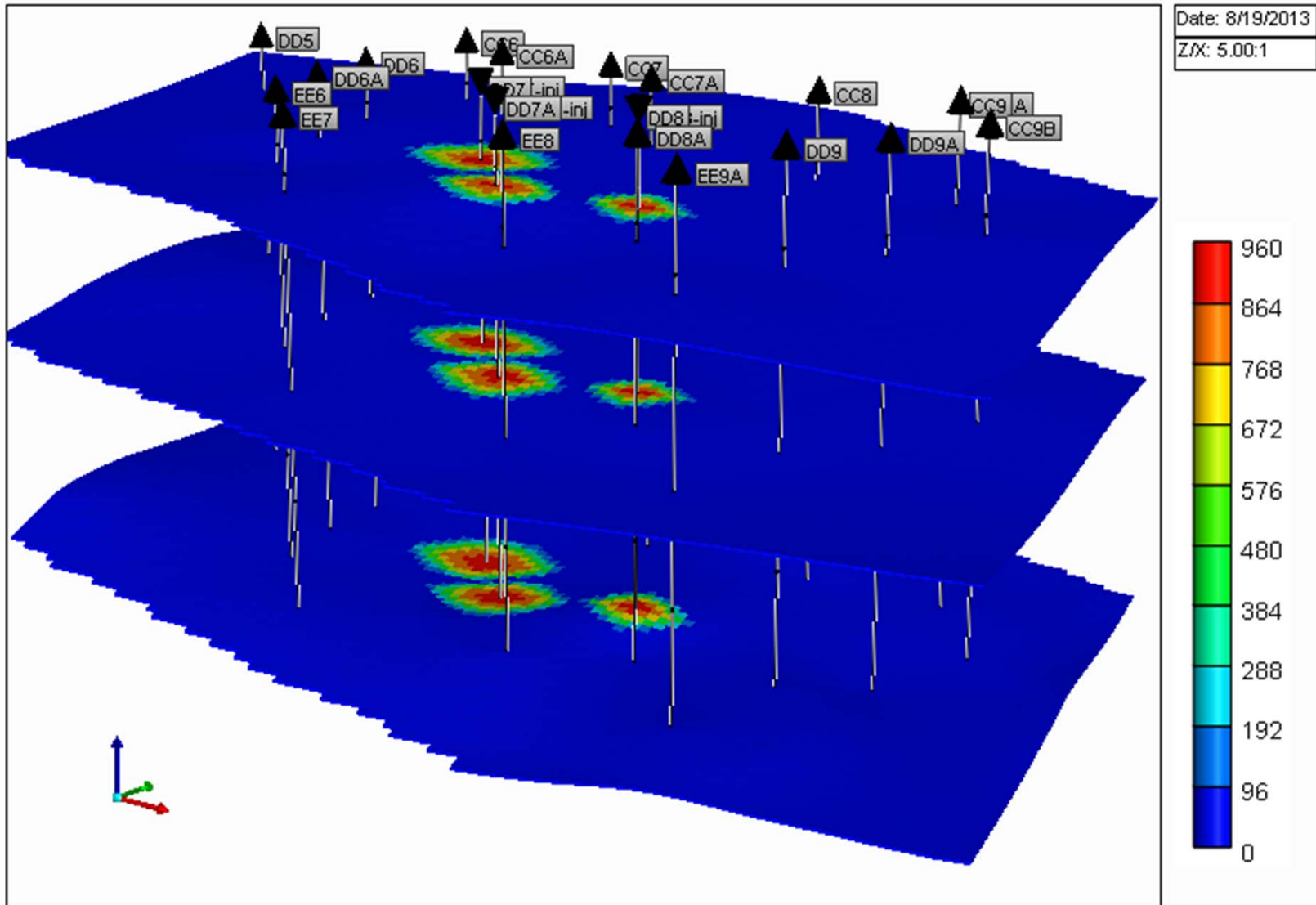
# Bottom-Hole Constraint equal in each Well

Adsorption(CO2) (gmole/m3) 2014-10-01 K layer: 5

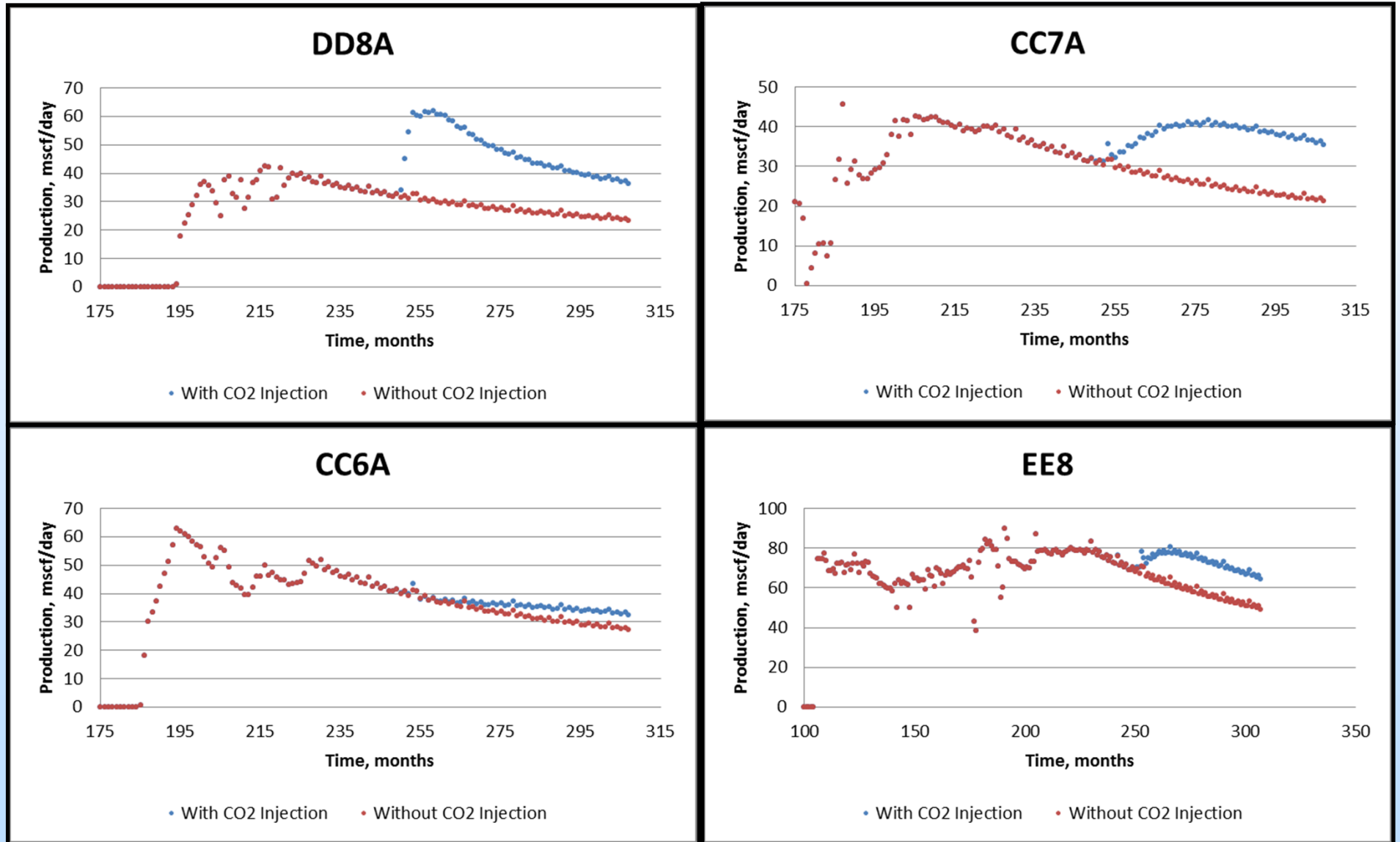


# CO2 Plume by Layer

Adsorption(CO2) (gmole/m3) 2014-10-01



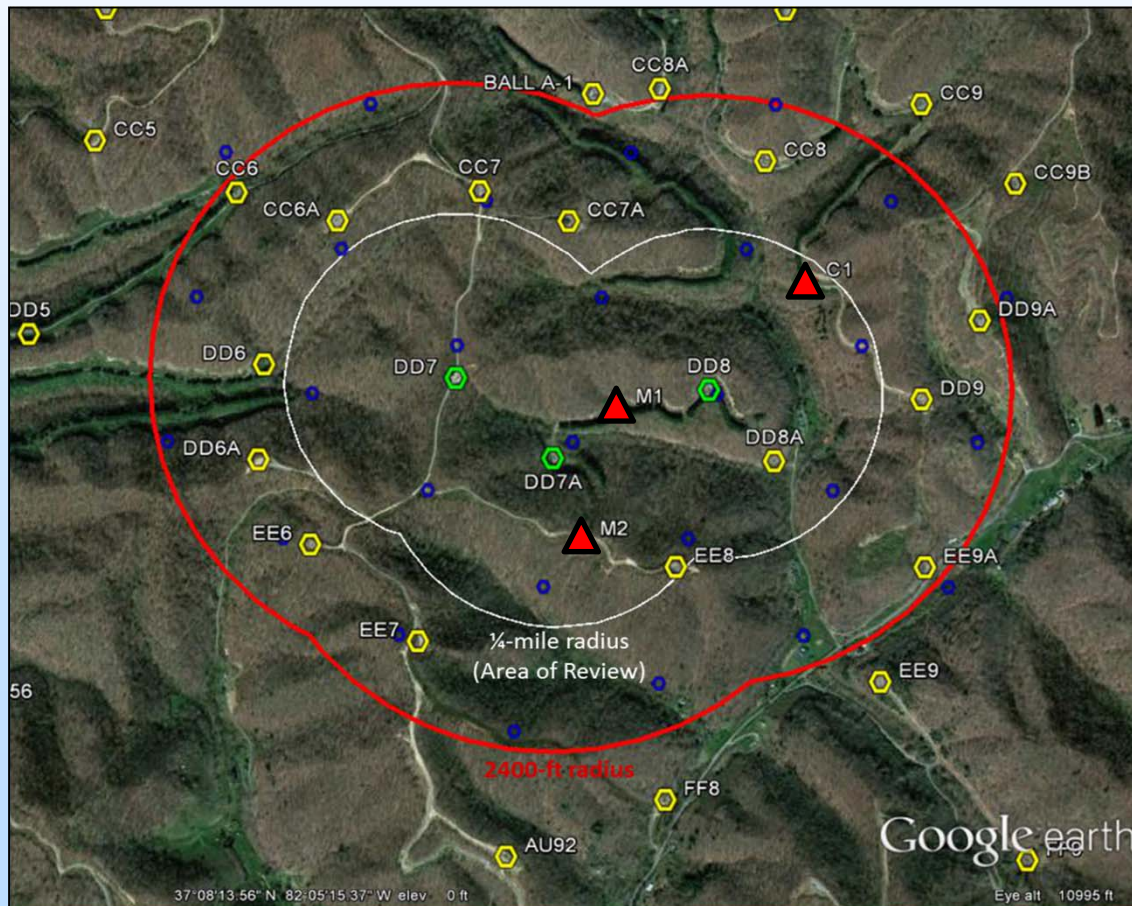
# ECBM after 1 and 4 Years Post-Injection: 22 – 106 MMcf



# MVA program for Buchanan County test

## Repeated from Russell County test:

- Atmospheric monitoring, Soil Flux, surface water sampling and shallow tracer detection
- Offset well testing for gas composition (CO<sub>2</sub> concentration, tracers, ECBM)
- Injection logging



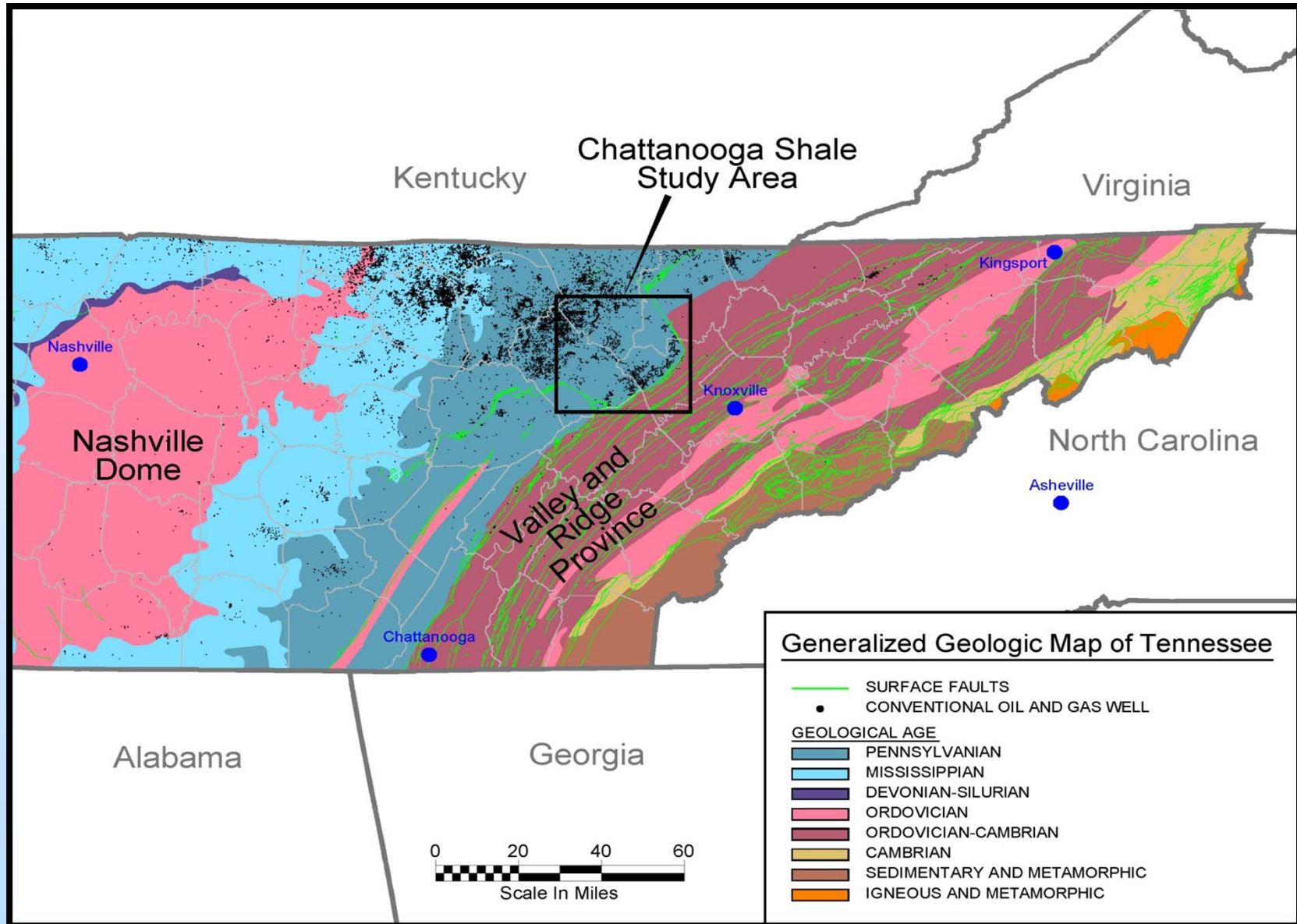
## New components:

- Multiple tracer injections
- 3 monitoring wells by multiple zone
- Surface deformation measurement
- **Tomographic fracture imaging**
  - Passive measurement of seismic energy emissions (similar to microseismic monitoring)

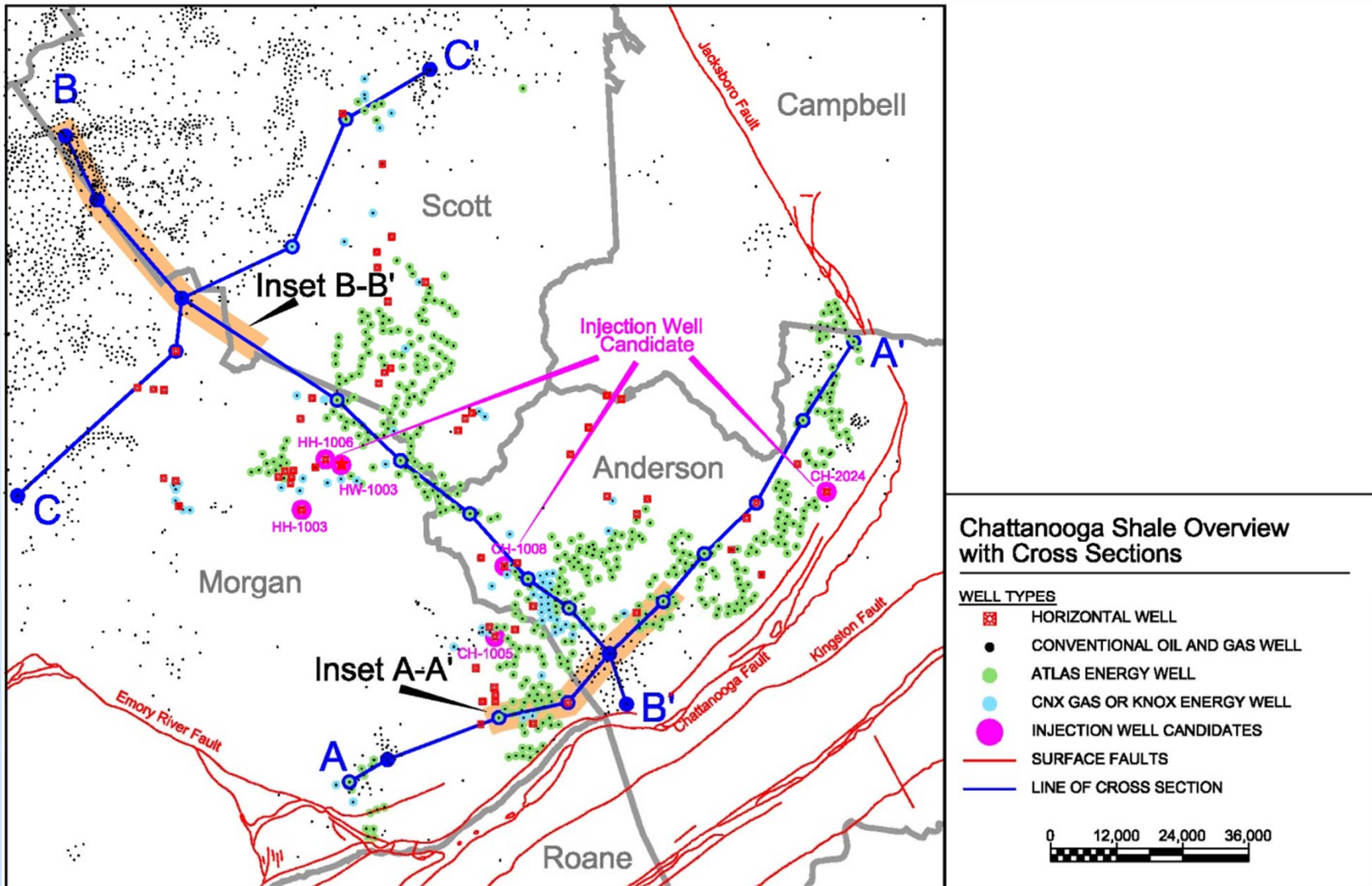
# Shale Test – Site Selection

- West Virginia Targets: Lower Huron and Marcellus Shale
- Virginia Targets: Lower Huron Shale
- **Tennessee Targets: Chattanooga Shale**
- Selection Criteria
  - Ownership / Access
  - Vertical vs. Horizontal
  - Co-Mingled Production
  - Production
  - Depth
  - Structure
  - Liquids Production
  - Completion and Stimulation

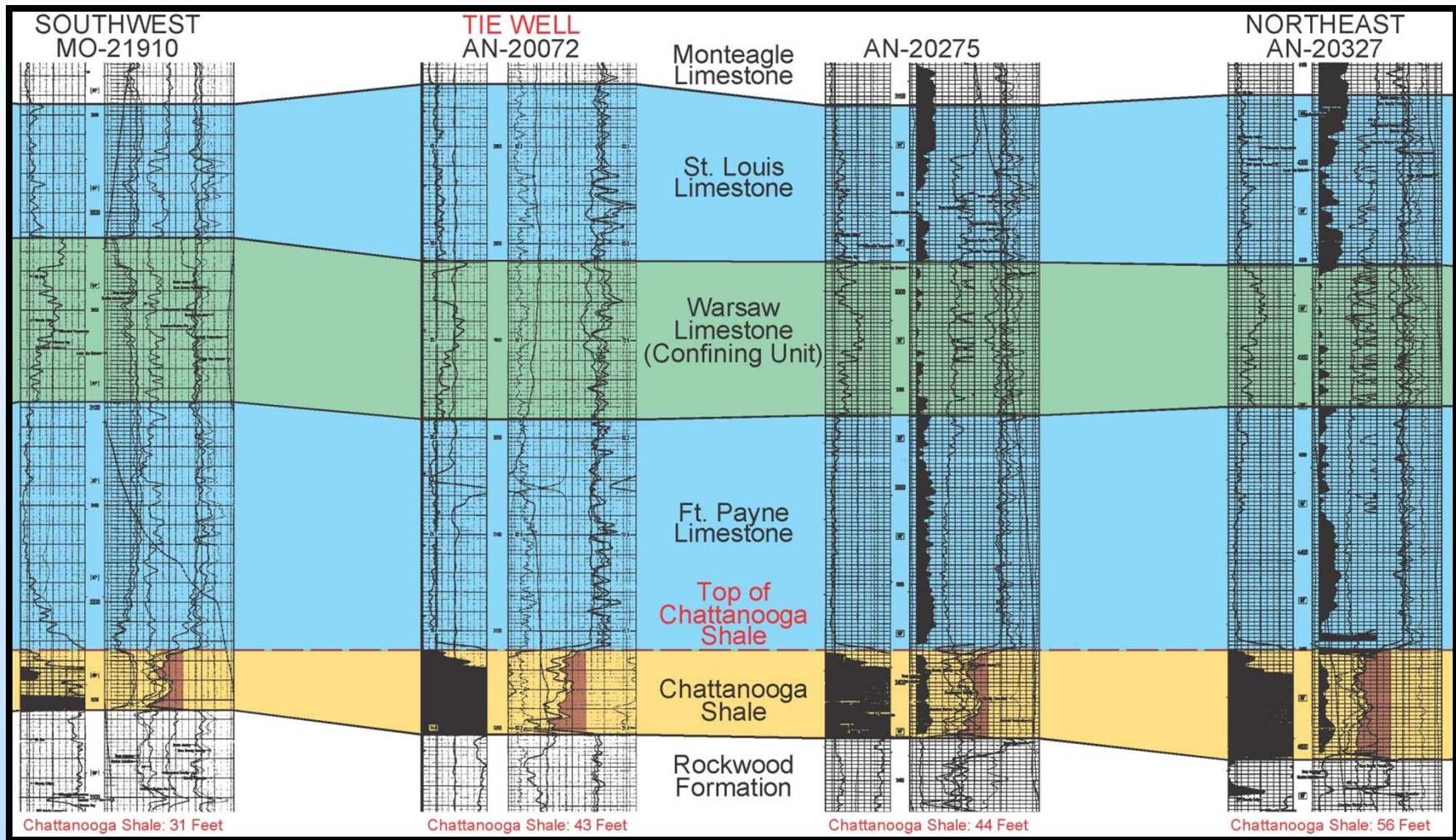
# Chattanooga Shale Study Area



# Chattanooga Shale Well Candidates

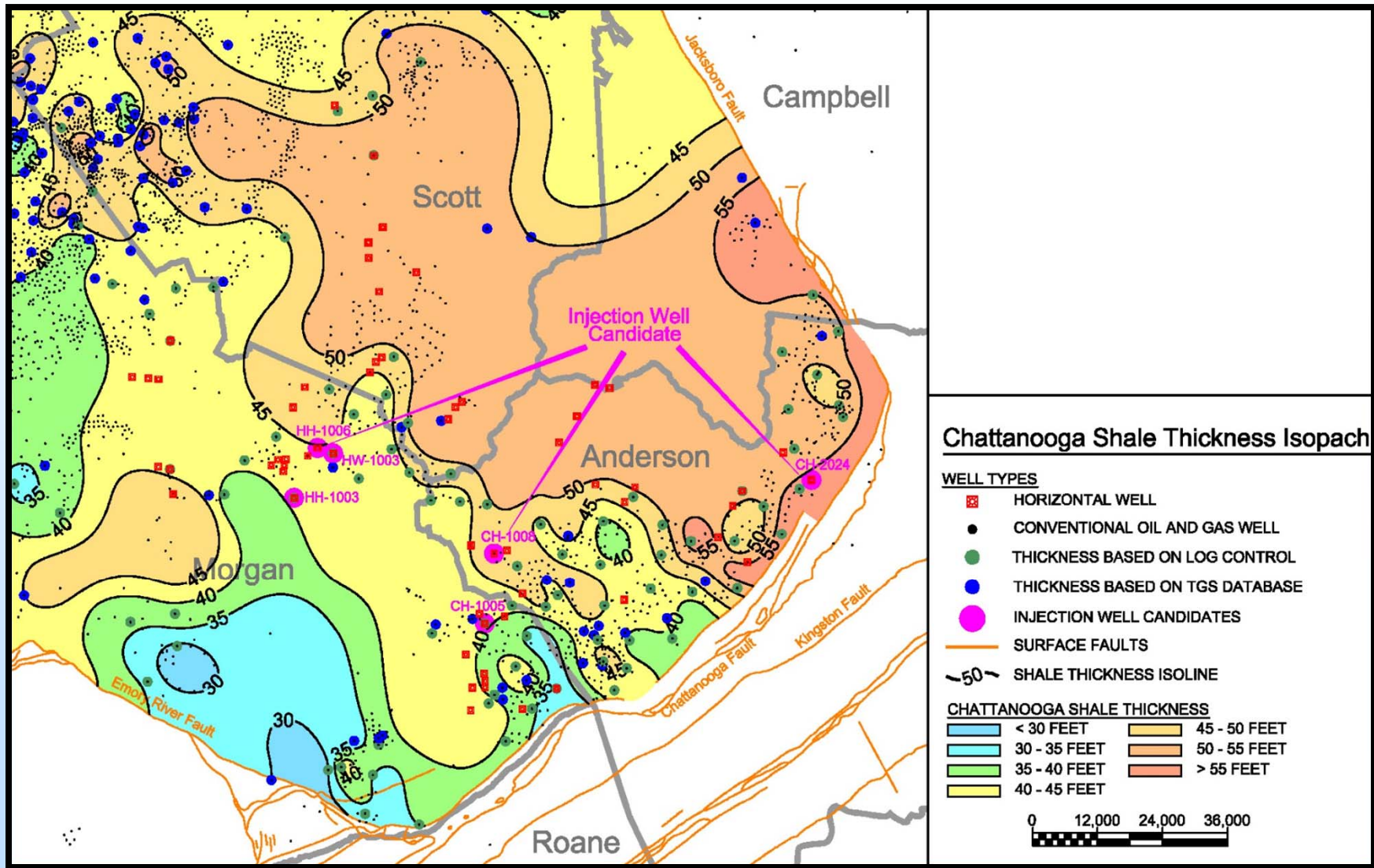


# Inset from Cross-Section

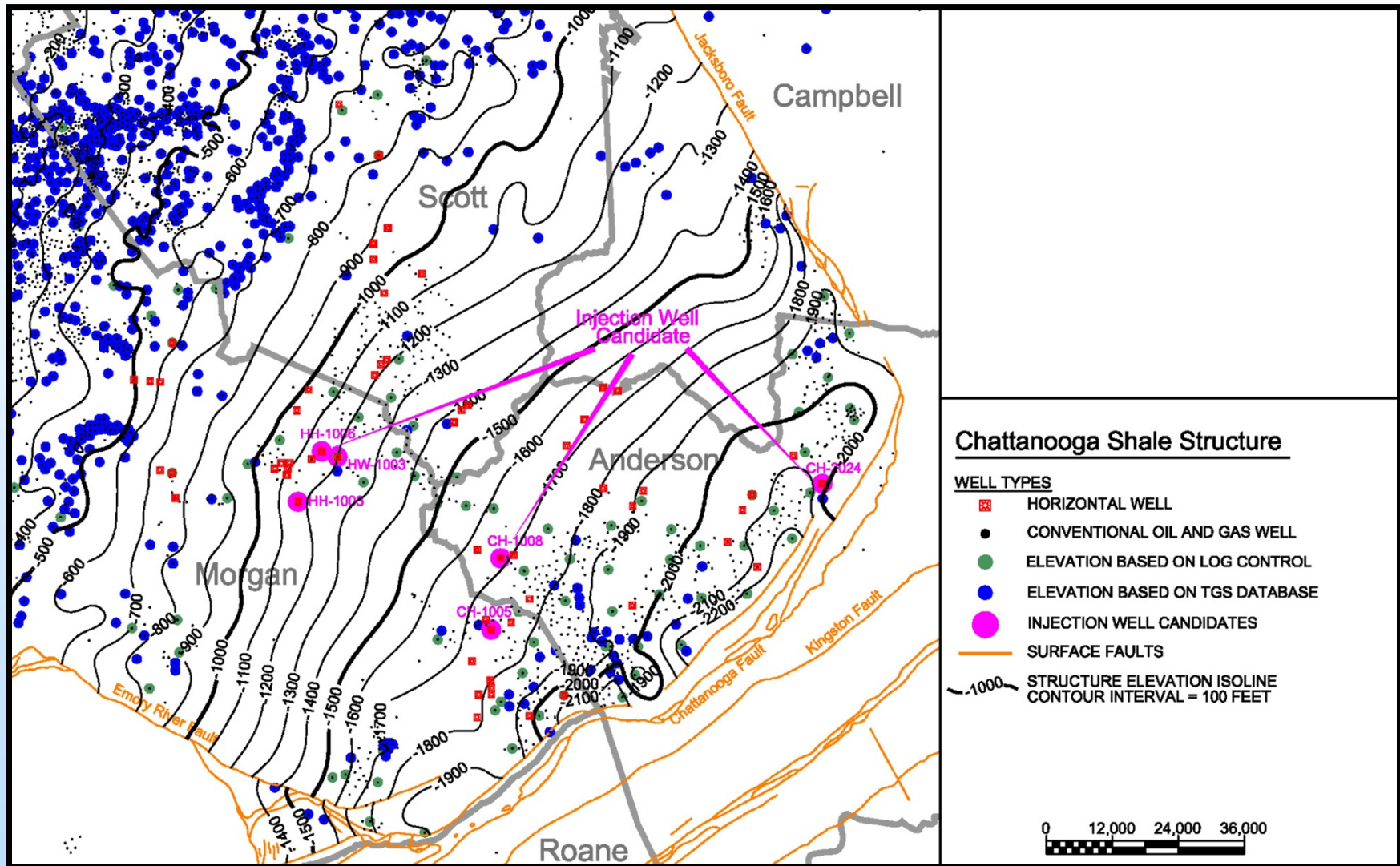




# Chattanooga Shale Thickness Isopach



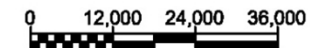
# Chattanooga Shale Structure Map



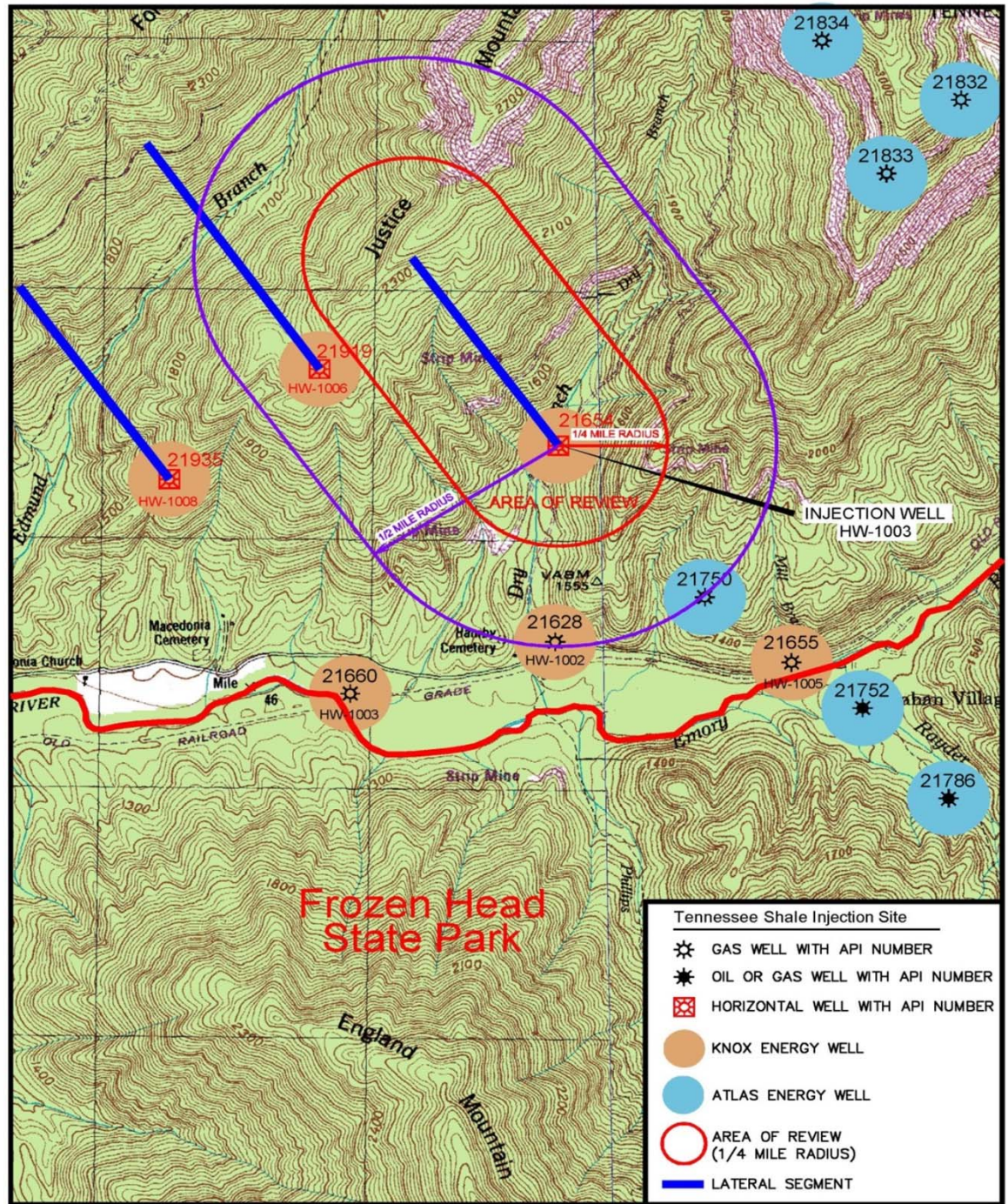
## Chattanooga Shale Structure

### WELL TYPES

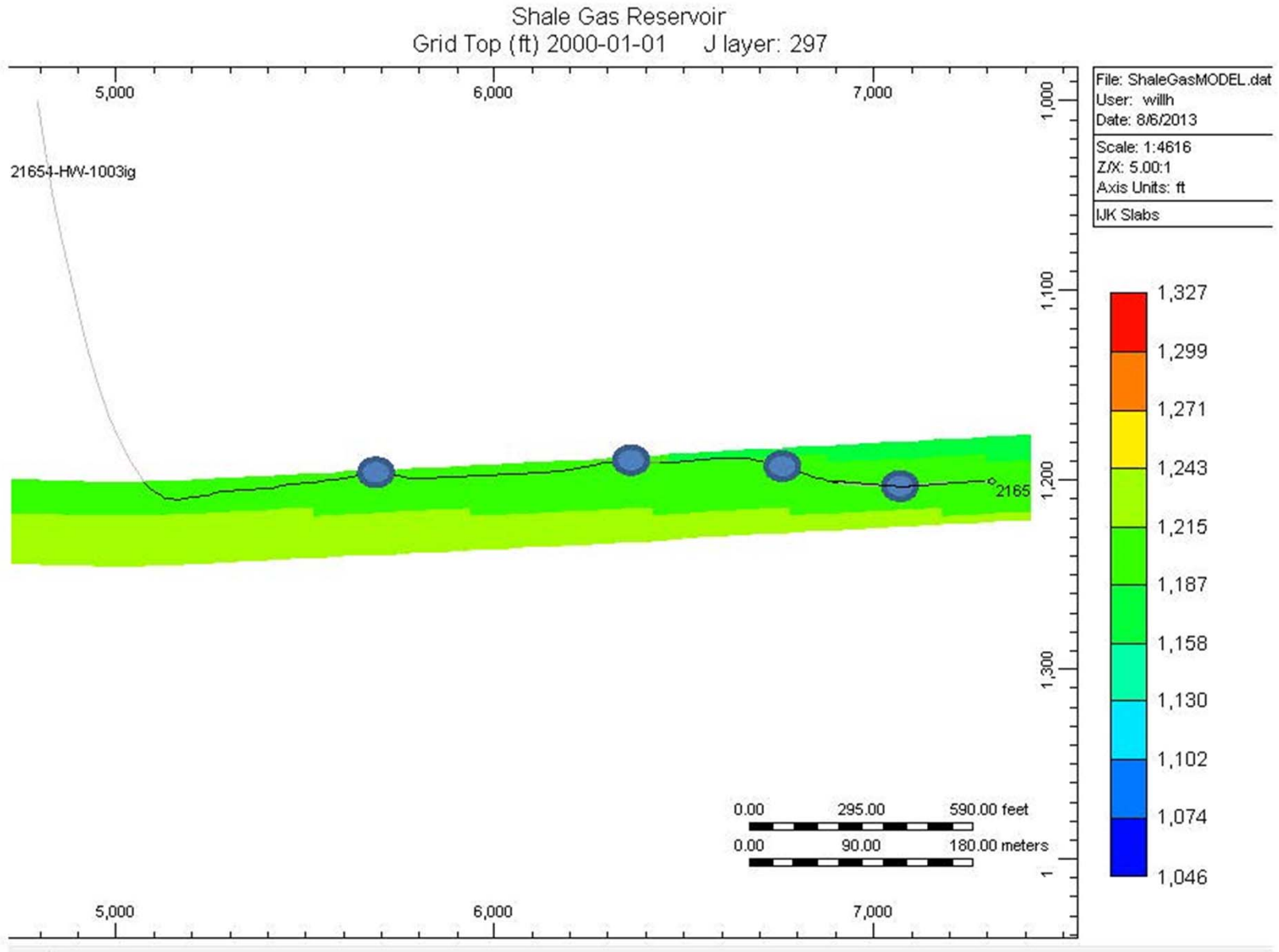
- HORIZONTAL WELL
- CONVENTIONAL OIL AND GAS WELL
- ELEVATION BASED ON LOG CONTROL
- ELEVATION BASED ON TGS DATABASE
- INJECTION WELL CANDIDATES
- SURFACE FAULTS
- 1000— STRUCTURE ELEVATION ISOLINE  
CONTOUR INTERVAL = 100 FEET



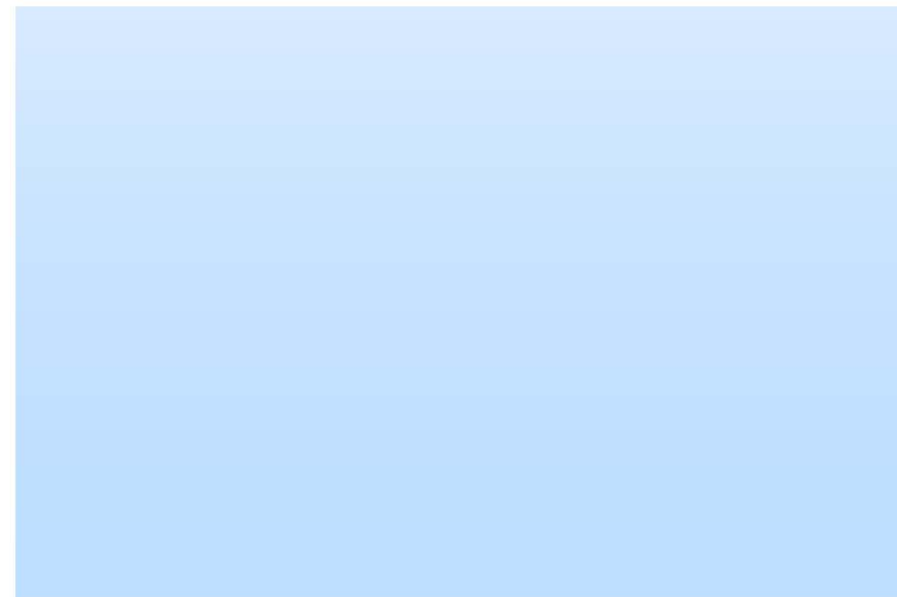
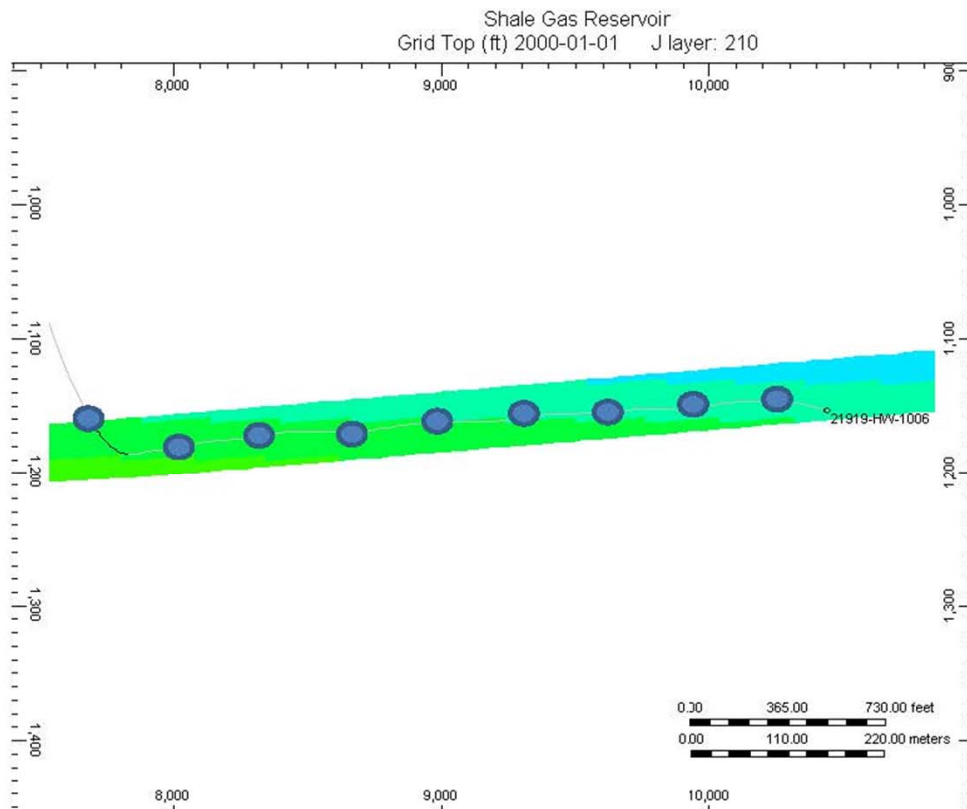
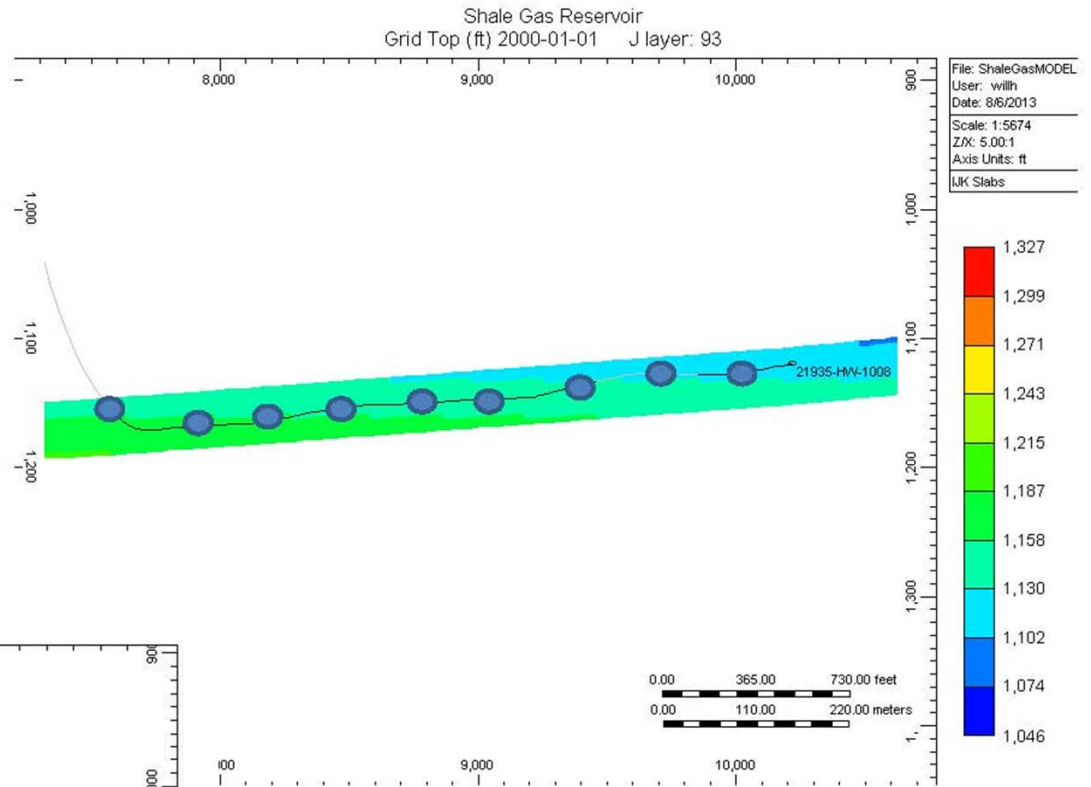
# Shale Test– Injection and Off-set Monitoring Well Locations

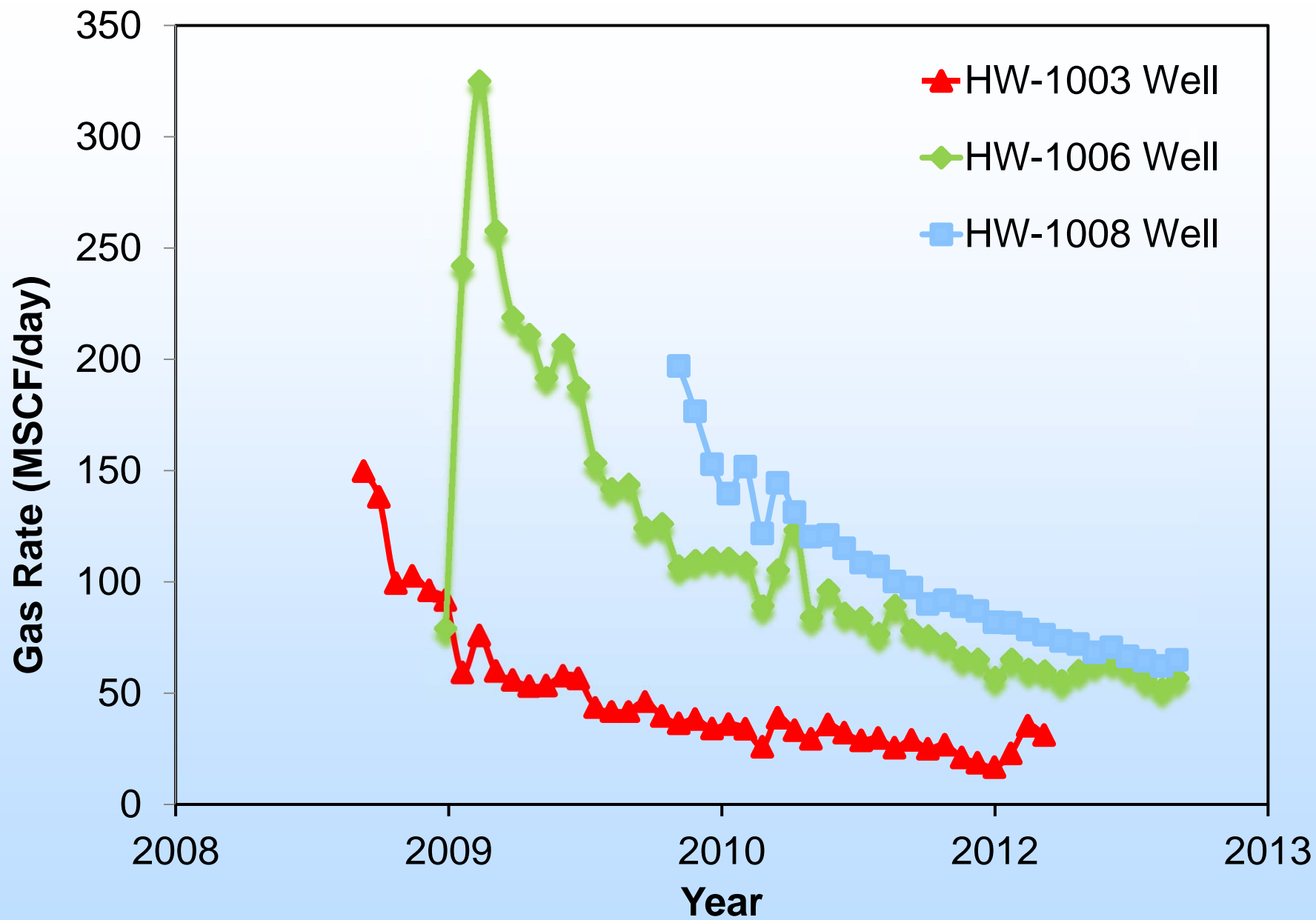


# Injection Well – 4 Stage



# Off-Set Wells – 9 Stages





# Accomplishments to Date

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- Completed Geologic Characterization for CBM Test Site
- Preliminary Geologic Characterization for Shale Test Site
- Site Selection of 3 CBM Wells in VA for Injection
- Site Selection of 1 Horizontal Shale Well in TN for Injection
- Access Agreements for CBM Test completed
- Access Agreements for Shale Test completed
- Conducted Risk Workshop and developed Risk Register
- Performed detailed reservoir modeling analysis and assessment for CBM Test
- Performed preliminary reservoir modeling analysis for Shale Test
- Developed Drilling, Monitoring and Injection Plans
- Initiated Public Outreach Plan

# Summary

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- Lessons Learned: Timing of multiple moving parts is extremely important
  - Site Selection
  - Access Agreements – Landowner/Mineral Owner/Operator
  - Permitting – UIC Process
  - Design
- Future Plans
  - Drill Monitoring Wells – October 2013
  - Injection!
    - Coal Test – 1/1/2014
    - Shale Test – 11/1/2013



# Appendix

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# Benefit to the Program

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- Develop technologies that will support industries' ability to predict CO<sub>2</sub> storage capacity in geologic formations to within  $\pm 30$  percent.
- Conduct field tests through 2030 to support the development of BPMs for site selection, characterization, site operations, and closure practices.
- The research project is testing the potential for enhanced coalbed methane (ECBM) and enhanced gas (EGR) production and recovery
- The technology, when successfully demonstrated, will provide guidance for commercialization applications of ECBM and EGR

Task Name	Deliverables	Funding	Phase I				Phase II				Phase III							
			FY 2012				FY 2013				FY 2014				FY 2015			
			Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
<b>Task 1.0--Project Management and Planning</b>	Updated Project Management Plan	\$741,678																
<b>Task 2.0--Site Selection and Access Agreements</b>	Site Selection Memo and Access Agreements	\$691,528																
2.1--Initial Site Screening and Selection	CO2 Procurement Plan																	
2.2--Leases, Agreements, Permitting, etc.	Permitting Action Plan																	
2.3--Outreach and Education	Public Outreach Plan																	
<b>Task 3.0--Site Characterization, Modeling, and Monitoring</b>	Site Characterization, Modeling, and Monitoring Plan	\$3,217,450																
3.1--Detailed Geologic Characterization	Catalog of Well Logs File																	
3.2--Reservoir Modeling	Well Drilling and Installation Plan																	
3.3--Exploratory Characterization and Monitoring Wells	MVA Plan																	
3.4--Monitoring, Verification and Accounting																		
<b>Task 4.0--Risk Analysis</b>	Risk assessment and mitigation plan	\$216,095																
4.1--Develop Risk Register																		
4.2--Develop Risk Assessment and Mitigation Plan																		
4.3--Management of Risks																		
4.4--Update and Reassess Risk Plan																		
<b>Task 5.0--Injection Design and Planning</b>	Site Development, Operations, and Closure Plan	\$558,891																
5.1--Test Site Operations																		
5.2--Design of Monitoring Wells																		
5.3--Design of Injection Wells																		
<b>Task 6.0--Pre-injection Site Preparation</b>	Implementation Status Report	\$2,973,479																
6.1--Conversion of Production Wells																		
6.2--Conversion of Characterization/Monitoring Wells																		
6.3--Construction of Facilities																		
6.4--Monitoring																		
<b>Task 7.0--Injection Operations</b>	Quick-look Memo Mid-term Memo	\$4,391,325																
7.1--Injection Tests																		
7.2--Reservoir Monitoring																		
7.3--Surface Monitoring																		
7.4--Reservoir Modeling and Verification																		
<b>Task 8.0--Post Injection Monitoring and Analysis</b>	Updated Site Characterization/ Conceptual Models Plan	\$816,057																
8.1--Post-injection Monitoring																		
8.2--Interpretation and Assessment																		
<b>Task 9.0--Closeout/Reporting</b>	Commercialization Plan Best Practices Plan	\$767,588																
9.1--Closure of Site(s)																		
9.2--Reporting																		

# Bibliography

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- Journal:

- Gilliland, E.S., Ripepi, N., Conrad, M., Miller, M., and M. Karmis, Selection of monitoring techniques for a carbon storage and enhanced coalbed methane recovery pilot test in the Central Appalachian Basin, *International Journal of Coal Geology*, <http://dx.doi.org/10.1016/j.coal.2013.07.007>

- Publications:

- Vasilikou, F., C. Keles, Z. Agioutantis, N. Ripepi and M. Karmis, Experiences in Reservoir Model Calibration for Coal Bed Methane Production in deep coal seams in Russell County, Virginia, Proceedings, Symposium on Environmental Considerations in Energy Production, SME, April 14-18, 2013, Charleston, West Virginia. Proceedings: Pages 140-152.
- Vasilikou, F., C. Keles, Z. Agioutantis, N. Ripepi and M. Karmis, Model Verification of Carbon Dioxide Sequestration in Unminable Coal Seams with Enhanced Coal Bed Methane Recovery, 23rd World Mining Congress, August 11-15, 2013, Montreal, Canada. Proceedings.
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