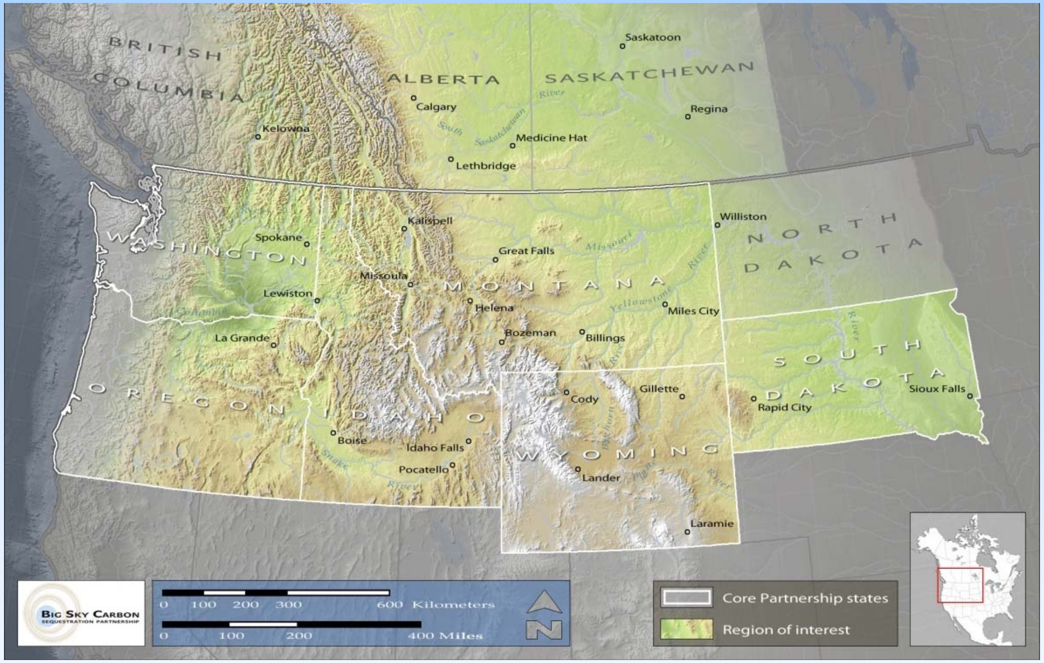
Big Sky Carbon Sequestration Partnership
Annual Partnership Meeting



Lee Spangler, David Bowen
October, 2008
Pittsburgh, PA

BIG SKY CARBON SEQUESTRATION PARTNERSHIP

NETL

MONTANA STATE UNIVERSITY

Project Performers

- Montana State University – Prime Contractor
- Columbia University
- Idaho State University
- University of Idaho
- University of Wyoming
- Schlumberger
- Cimarex Energy
- Idaho National Laboratory
- Los Alamos National Laboratory
- Lawrence Livermore National Laboratory
- Pacific Northwest National Laboratory

Project Elements - Management

Management

Lee Spangler, Director, PI
John Talbott, Project Manager
Lindsey Waggoner, Outreach Coordinator
Phil Smith, Fiscal Manager
Jennifer Kelley, Program Coordinator

Technical Leaders

David Bowen, Geologic lead
Pete McGrail, Technical lead – Basalts
Eric Robertson, Technical lead – ECBM
Scott Hughes, Mafic Rock Atlas
John Antle, Economics lead
Elizabeth Helmke, GIS co-leads
Pamela Tomski/Joe Perkowski, Outreach and Regulatory co-leads

Project Elements - BSCSP Partners

Battelle
Boise State University
Bullivant Houser Bailey PC
Center for Advanced Energy Studies
Center of Energy & Economic Development
Cimarex Energy
Columbia University, Lamont-Doherty Earth Observatory
Crow Tribe
Det Kongelice Olje OgEnergidepartment
Edison Mission Group
Energy Northwest
EnTech Strategies, LLC
Environmental Financial Products
Environmental Protection Agency
Heller/Ehrman
IBM
Idaho Carbon Sequestration Advisory Committee
Idaho Dept. of Environmental Quality
Idaho National Laboratory
Idaho Soil Conservation Service
Idaho State University
Inland Northwest Research Alliance
Institute for Energy Technology (Norway)

Institute de Physique de Globe de Paris
Inter Tribal Timber Council
Jackson Hole Center for Global Affairs
Los Alamos National Laboratory
Montana Bureau of Mines and Geology
Montana Dept. of Environmental Quality
Montana Farm Bureau Federation
Montana GIS Services Bureau IT Services
Montana Governor's Office
Montana State University - Bozeman
Montana Tech
National Carbon Offset Coalition
National Geophysical Research Institute (India)
National Tribal Environmental Council
Nez Perce Tribal Council
Norwegian University of Science and Technology
Oregon State University
PacifiCorp
Portland General Electric (PGE)
Power Procurement Group
PPL Montana
Puget Sound Energy (PSE)
Ramgen Power Systems, Inc.
Research Council of Norway
Ruckelshaus Institute of Environment & Natural Resources
Russian Academy of Sciences

Sage Resources
Schulmberger
Semiarid Prairie Agricultural Research Center, Canada
Sintef Petroleum Research (Norway)
South Dakota School of Mines and Technology
Southern Montana Electric
State Geological Survey Units
Summit Energy
The Sampson Group
Unifield Engineering
United Power
University of Idaho
University of Wyoming GIS Center
University of Wyoming Enhanced Oil Recovery Institute
University of Idaho
Wageningen University (The Netherlands)
Western Governors' Association
Westmoreland Coal
Wyoming Carbon Sequestration Advisory Committee
Wyoming DEQ
Wyoming State Governor's Office
Yellowstone Ecological Research Center

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Phase III Large Volume Demonstration Project Goals

1. Evaluate the formation responses to injection of commercial volumes of supercritical CO_2 and derive the relevant MMV, modeling, risk assessment, and economic evaluation tools for future projects

2. Track the post-injection migration and containment of the CO_2 in the Nugget Sandstone to compare with pre-injection reservoir model predictions and use the data to refine multiphase flow reactive-transport modeling of CO_2 sequestration in saline formations

3. Evaluate the various MMV procedures used for their performance during deep sequestration. The depths in this project represent the upper limits of those proposed for Phase III projects, and may be used to help establish economic criteria for deep sequestration

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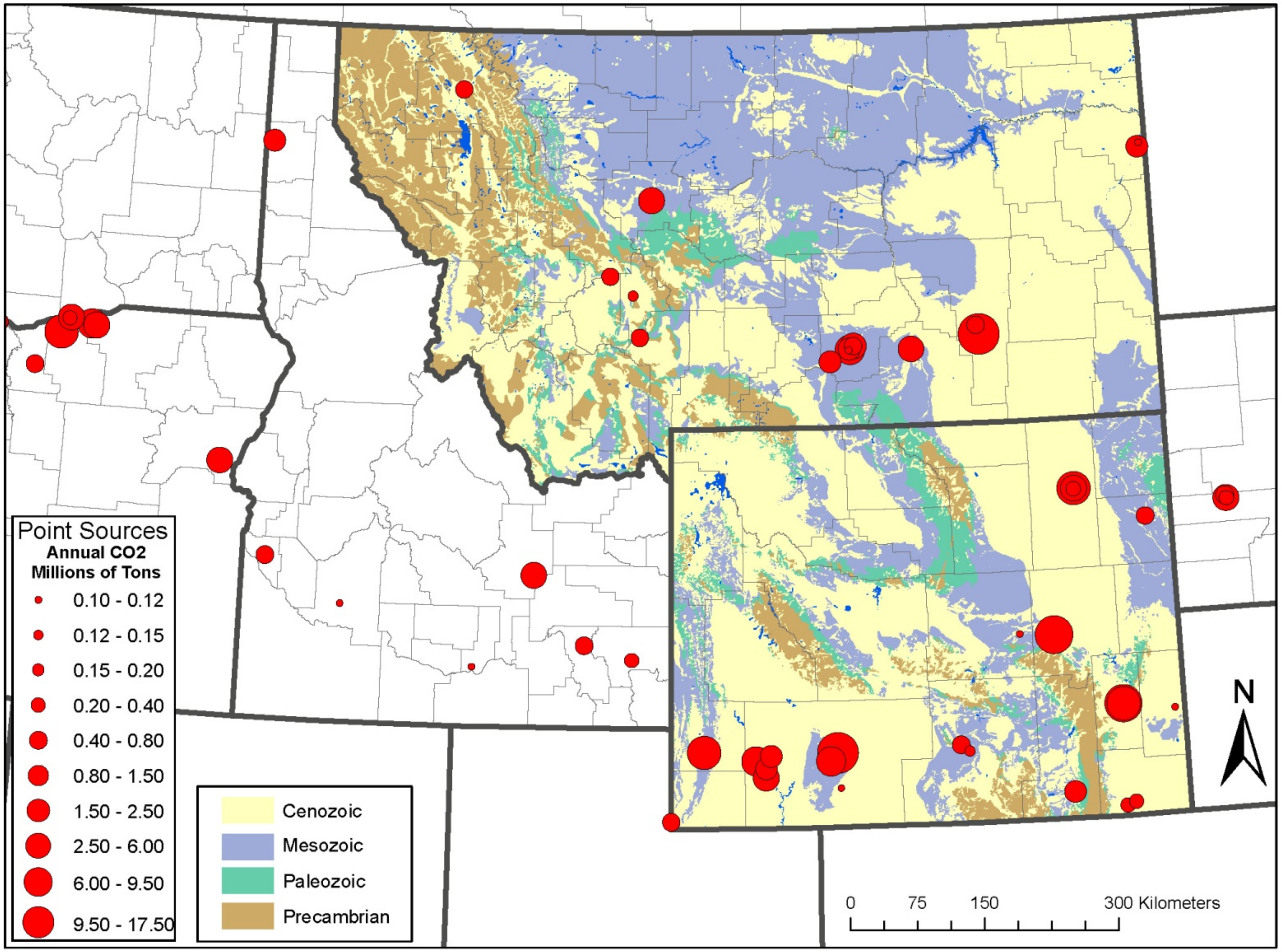
Pragmatic Issues

- Reasonably large quantity source of CO_2
- A good quality storage reservoir
- Good quality seal
- Top two in close proximity
- Anthropogenic source of CO_2 preferred
- Non-EOR preferred
- Potential for commercial use

Surface Geology and Point Sources



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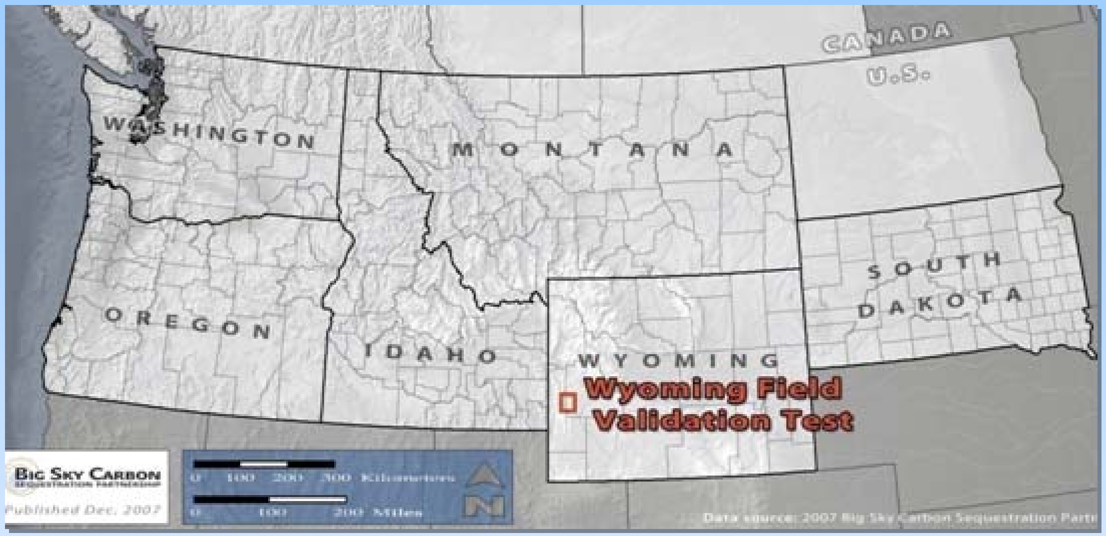
Phase III Large Volume Demonstration Project



- **Project Goal:** Demonstrate long-term safe storage of CO_2 into a regionally significant geologic sink
- **Site Description:** Riley Ridge Unit on the LaBarge Platform in SW Wyoming
- **Injection Target:** Nugget sandstone saline aquifer at ~11,000 feet
- **Source of CO_2:** Plan to inject 1-2 million tons of CO_2 from Cimarex Energy plant
- **Partners:** Montana State University, Columbia University, LANL, LLNL, Cimarex Energy, and Schlumberger

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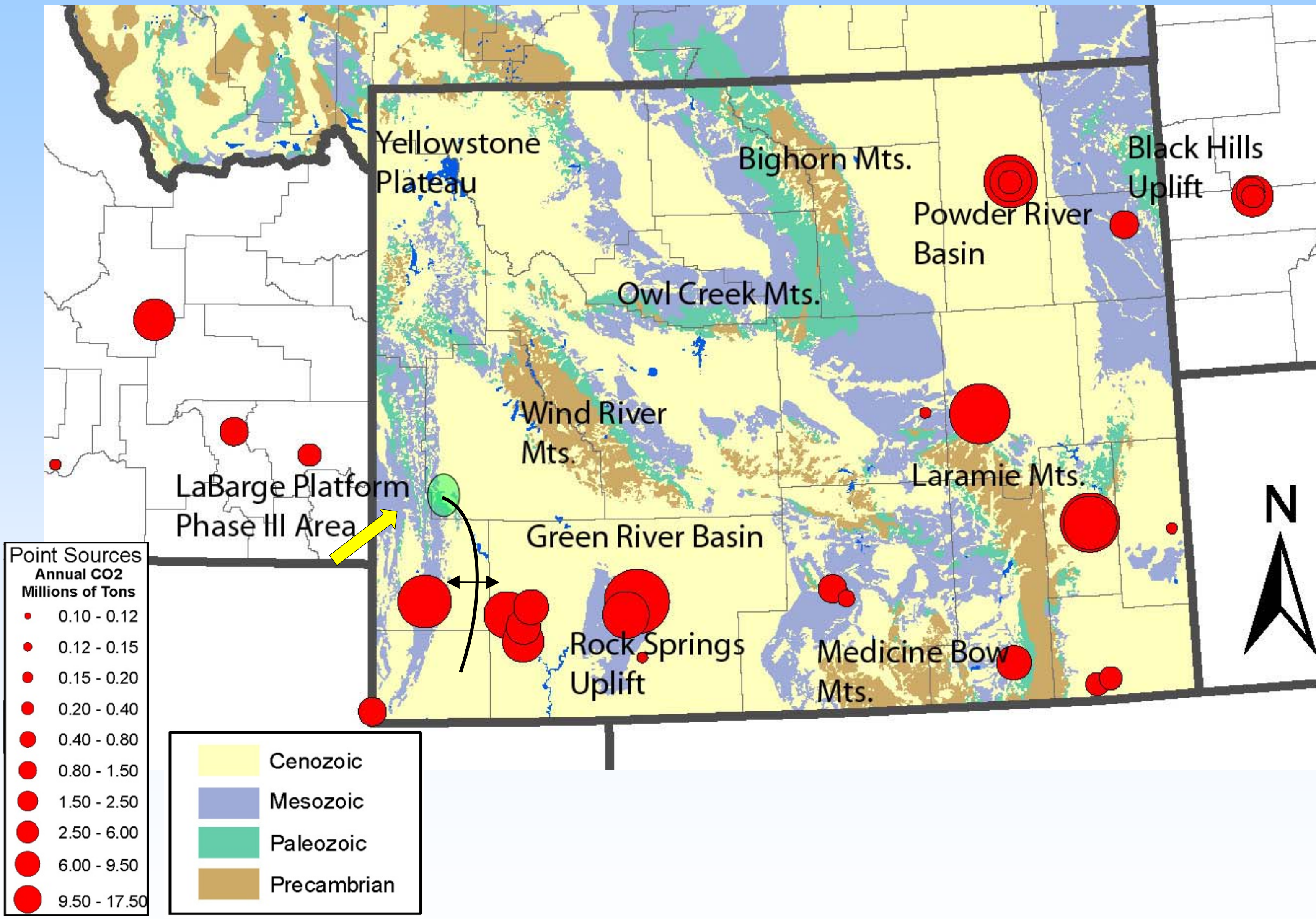
Location Map of Phase III Project



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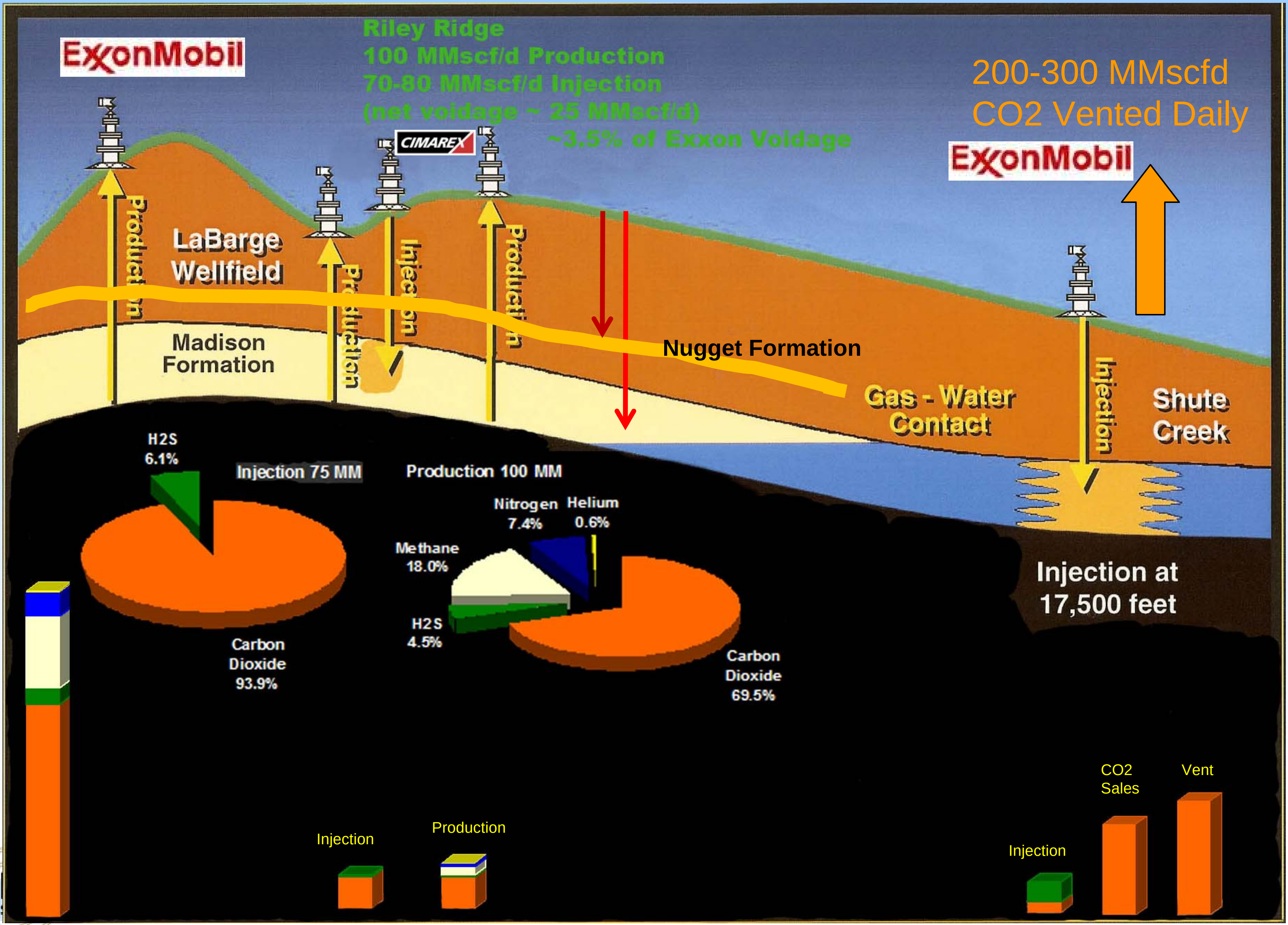
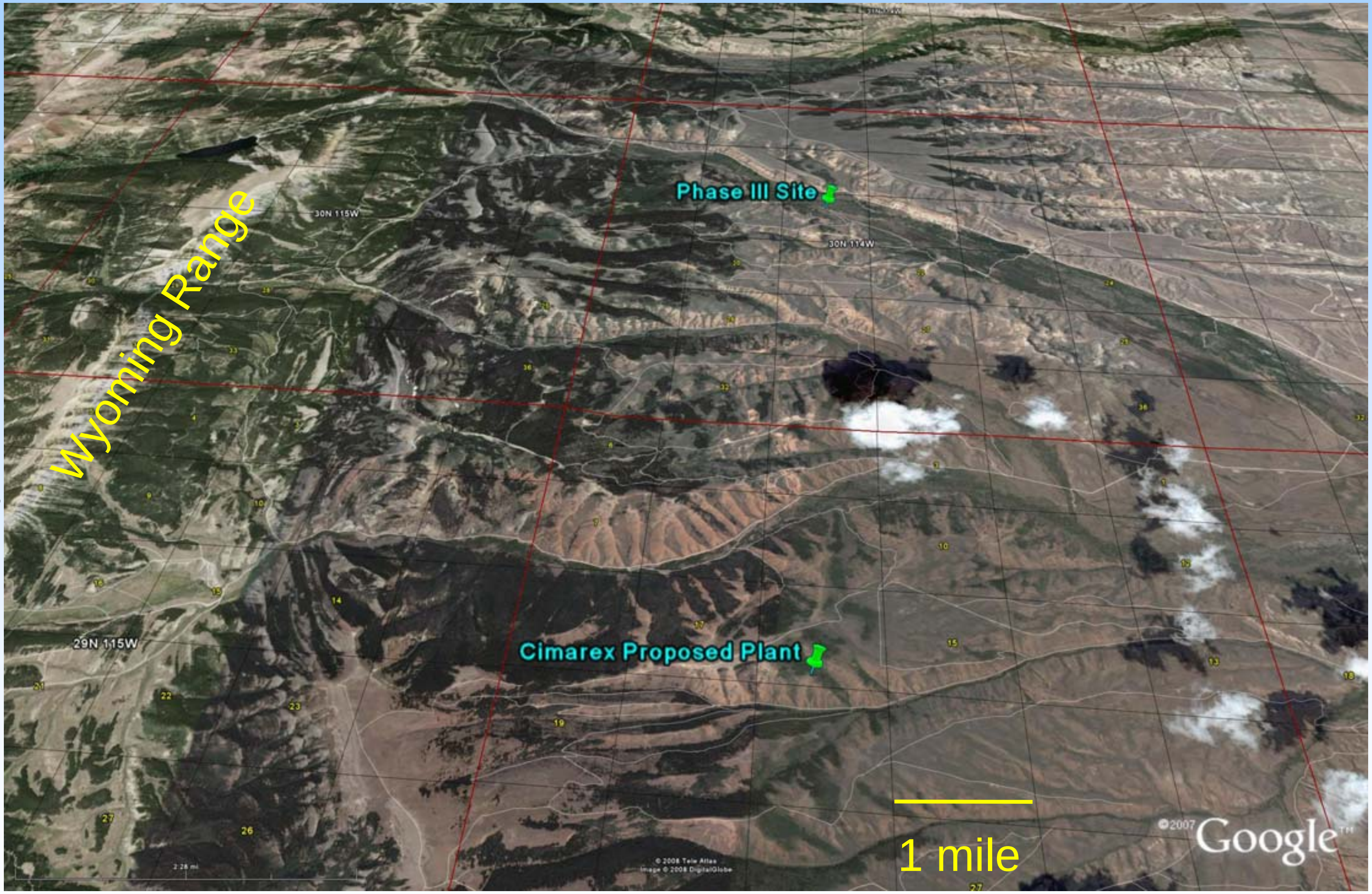
Wyoming Phase III Schematic



Proposed Project Site

- Cimarex Gas Plant on line in 2008 will produce and inject 75MMCFD of 92% CO_2 and 8% H_2S (3,947 tons of CO_2/day or 1.44 million tons/year)
- Drill a new injection well and monitoring wells to conduct test of Nugget saline aquifer
- Core from new wells will be used for analyses and flow testing



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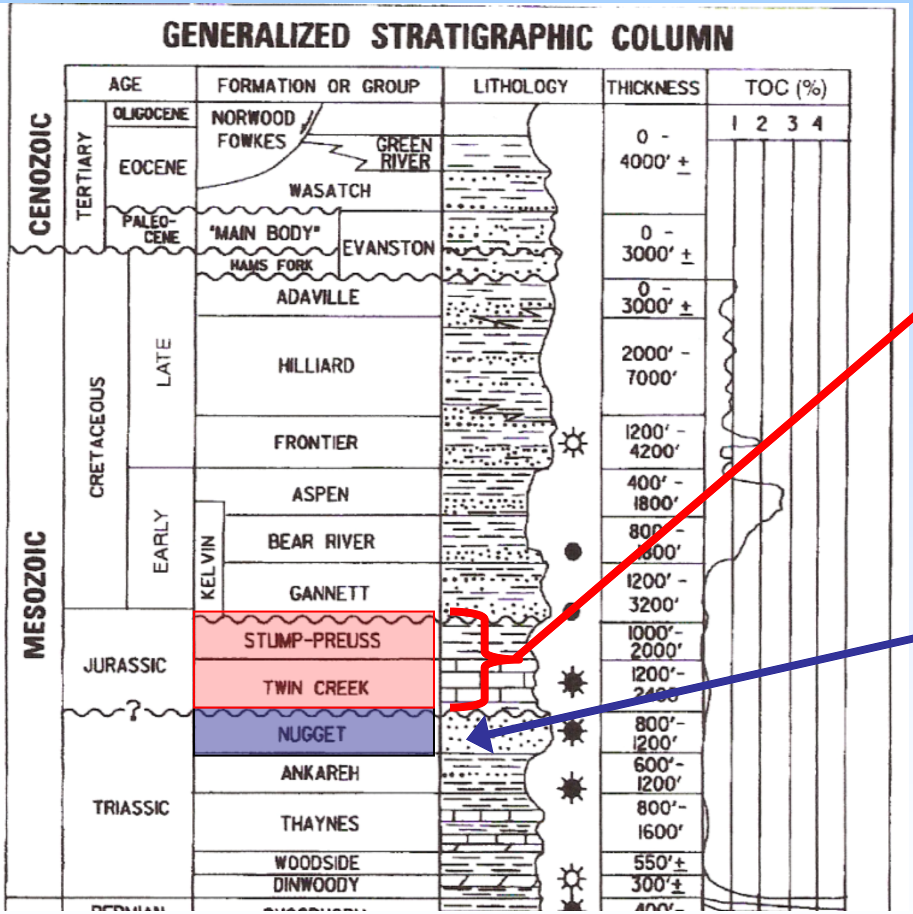
Southwest Wyoming Geology



Sealed by 75 feet of anhydrite and 1000 feet of Twin Creek LS and Stump-Preuss Shale

Target - Nugget Sandstone Saline Aquifer (100,000 TDS) 12% porosity, 70-300mD

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Critical Geologic Site Characteristics

- High Injectivity (reservoir permeability)
- Large Capacity (reservoir connectivity)
- High confidence in storage security (trap configuration and caprock integrity)

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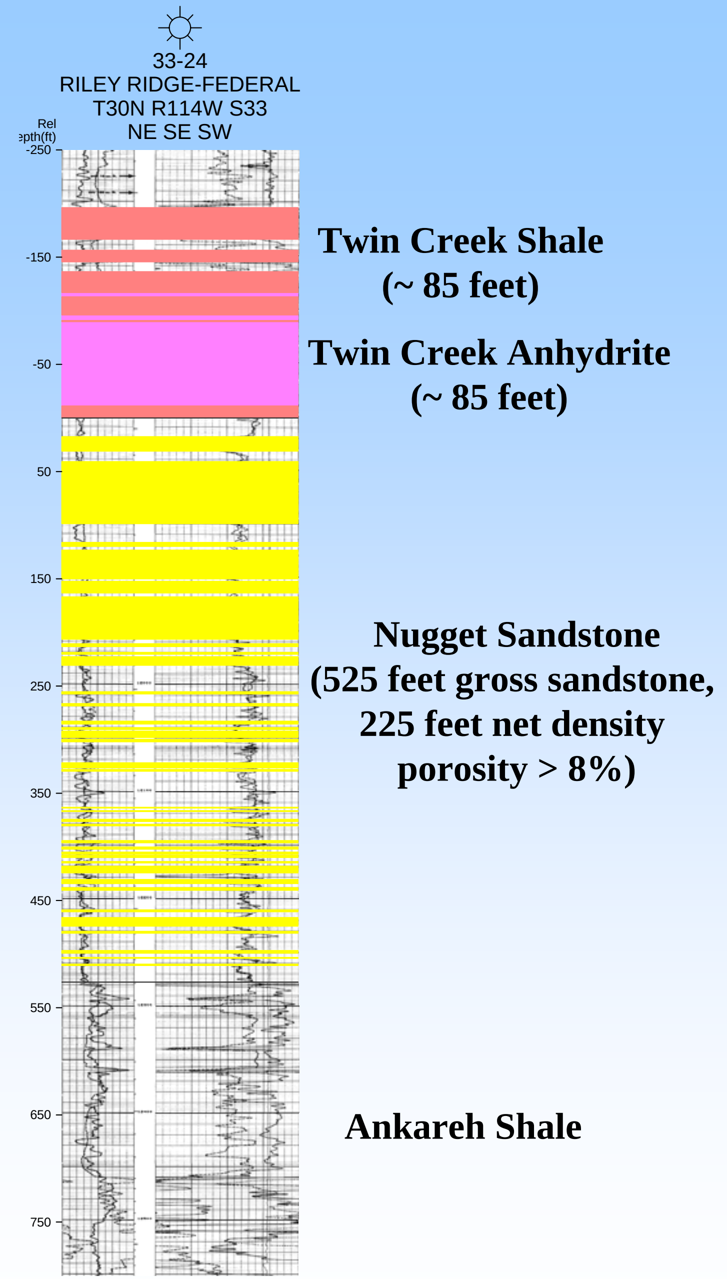
Regional Evidence for Site Quality – Rock Properties

- **Thick Anhydrite and Shale Topseal – demonstrated caprock for giant gas and oilfield traps in the overthrust belt to the west on structurally complex anticlines.**
- **Thick, high porosity, high permeability, quartz arenite sandstone reservoir**
- **Thick shale bottom-seal**



**Nearest Nugget penetration,
4 miles south of proposed injection site**

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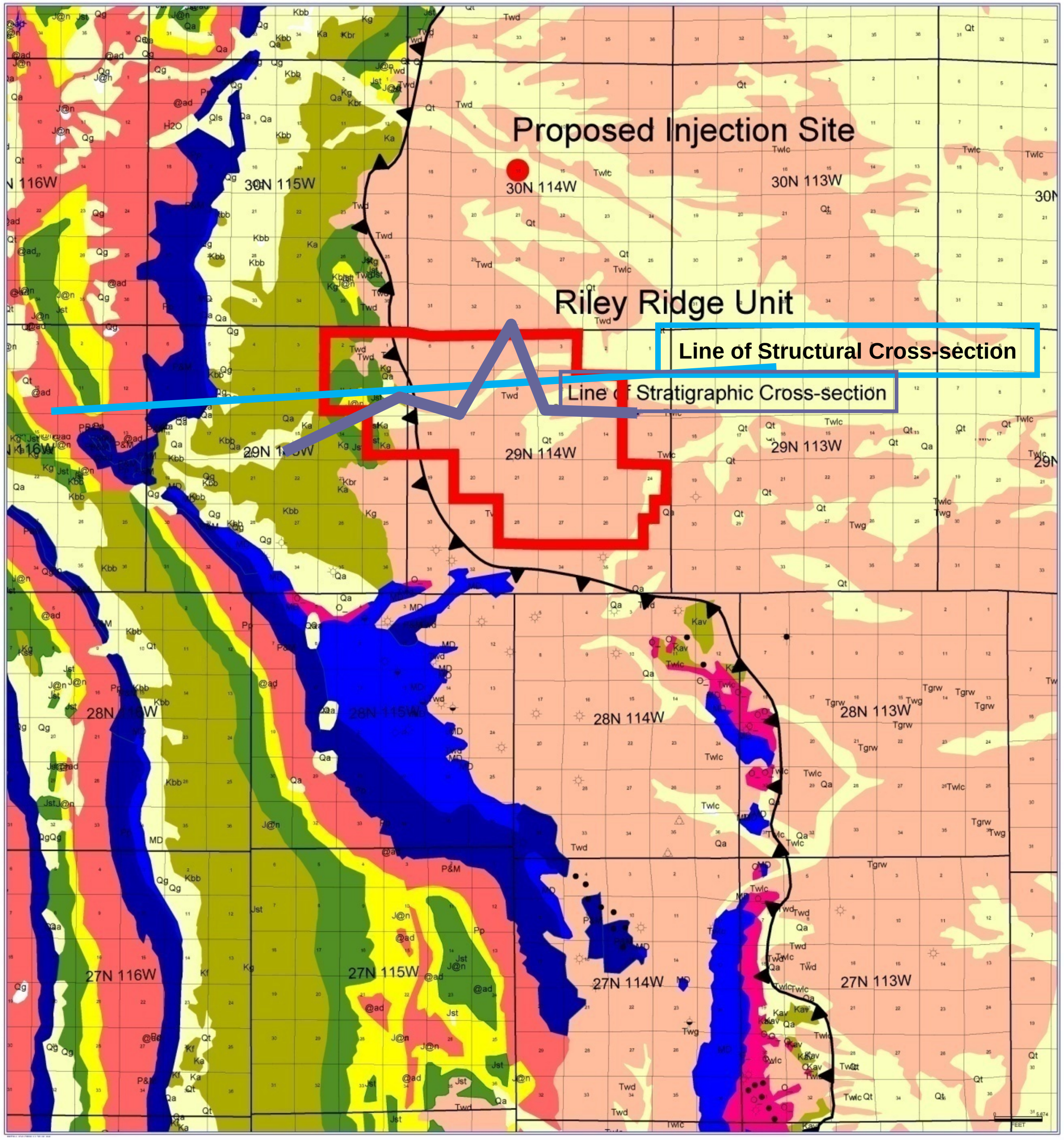
Regional Evidence of Site Quality

- Existence of water and gas injection wells into Nugget Sandstone – demonstrate adequate injectivity and compartment size.
  - Water Injection on LaBarge Platform: >40 million barrels of water (equivalent volume to 3.7 million tonnes CO2) into 1 well
  - Gas injection Overthrust Belt: injection rates greater than 30 million cubic feet/day into individual wells
- Multiple shallower and deeper oil and gas traps: proven trapping structure
- Giant Oilfields in the thrust belt to the west – same reservoir rocks and caprocks
- Favorable density of wellbores: ~ 1 well/10 square miles
- Existing cores of both reservoir and caprock

Surface Geology in the Area of the Phase III Pilot, LaBarge Platform, SW Wyoming



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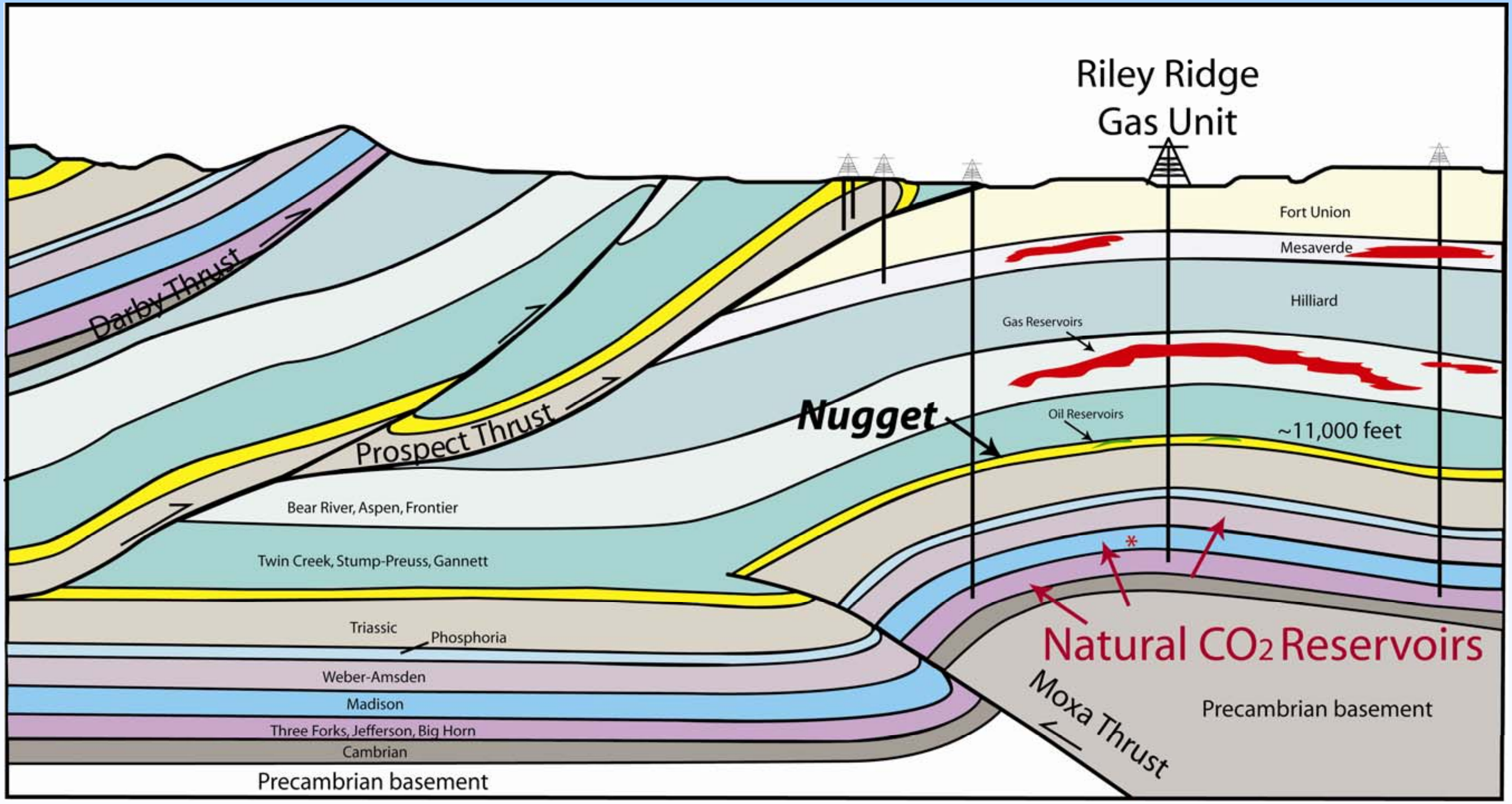
East-West Structural Cross-section across the LaBarge Platform / Riley Ridge Unit



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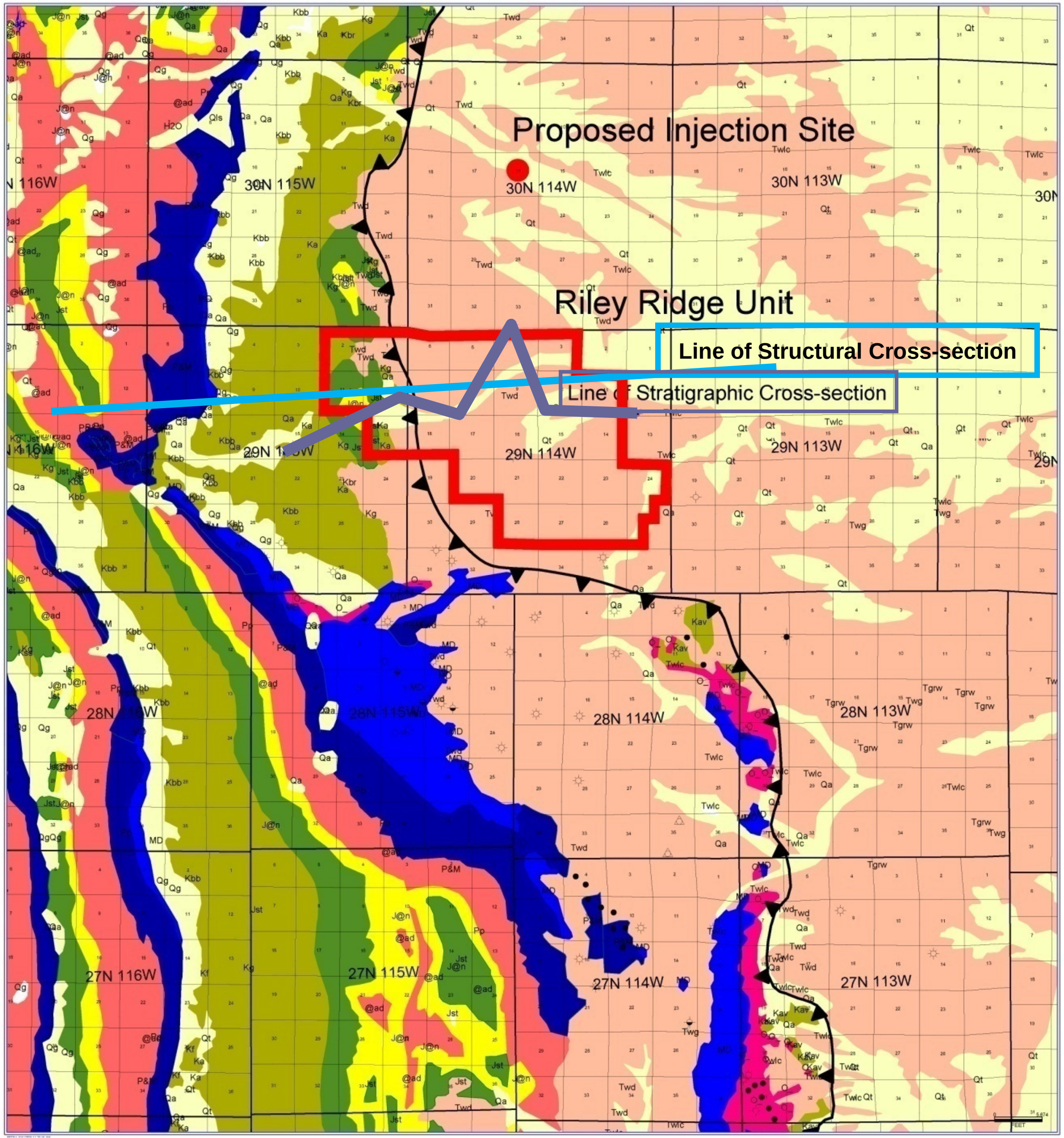

Good well control plus outcroping.

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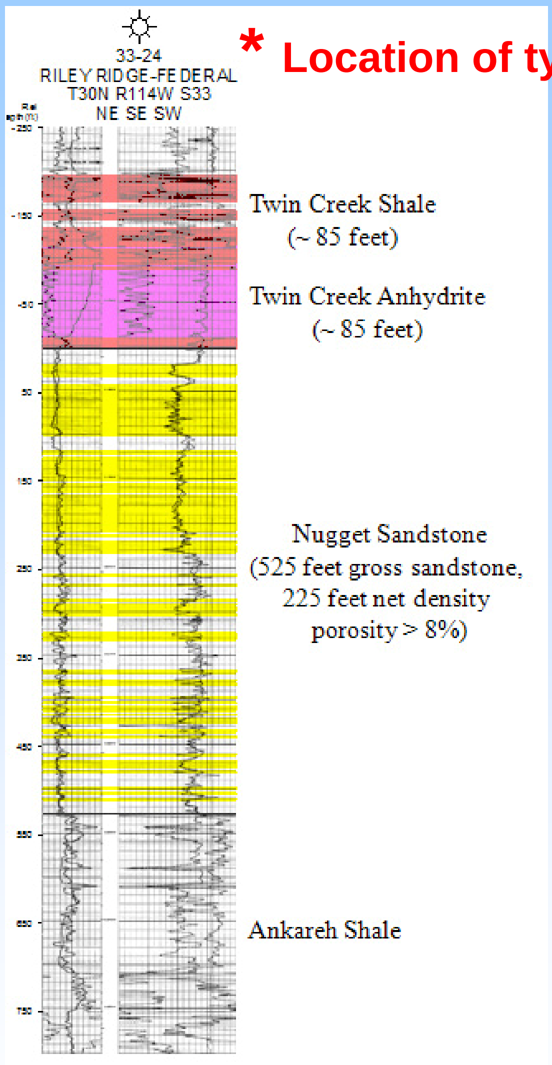
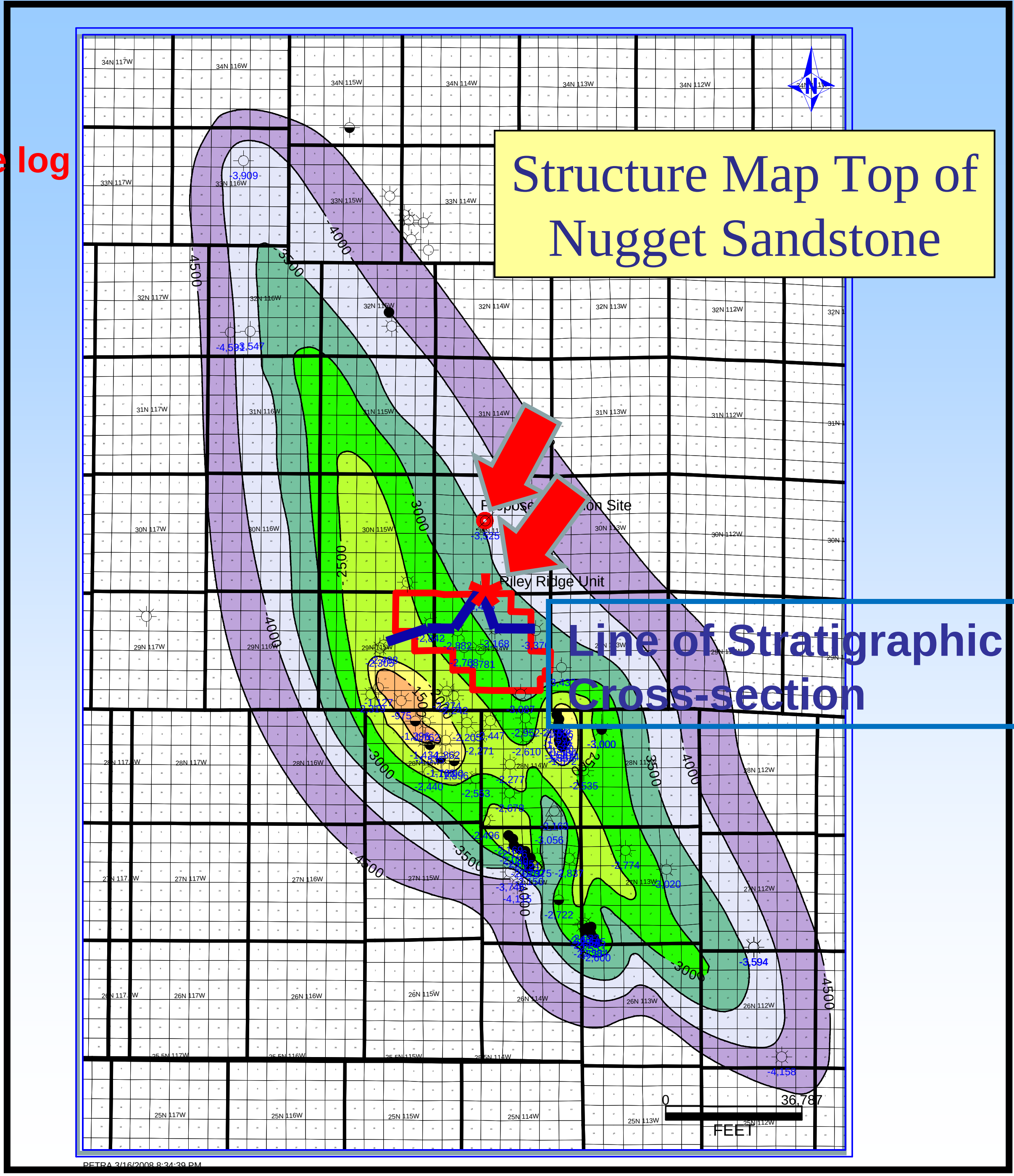
Type Log Nugget Reservoir Riley Ridge Unit

* Location of type log





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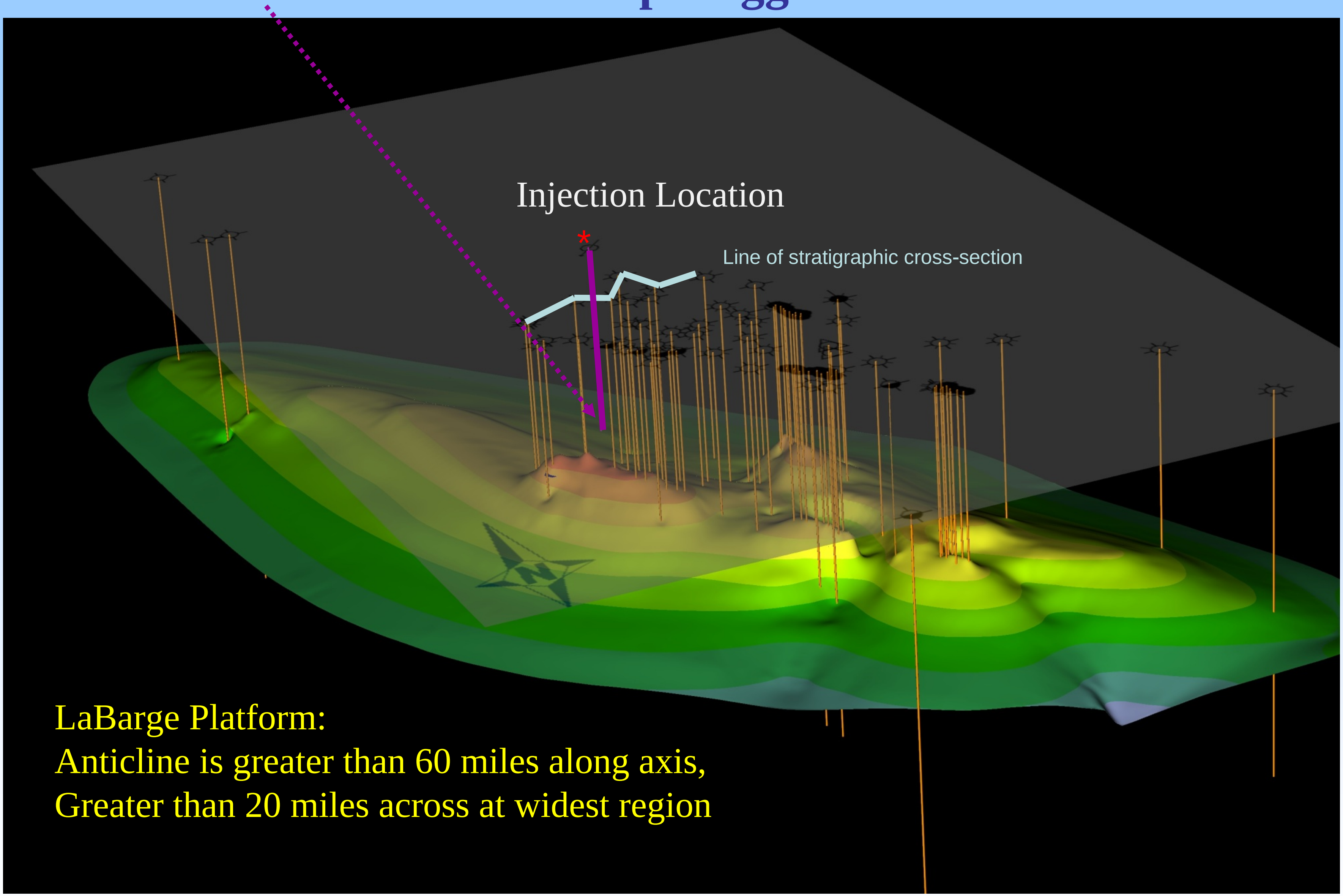
Structure Top Nugget Sandstone



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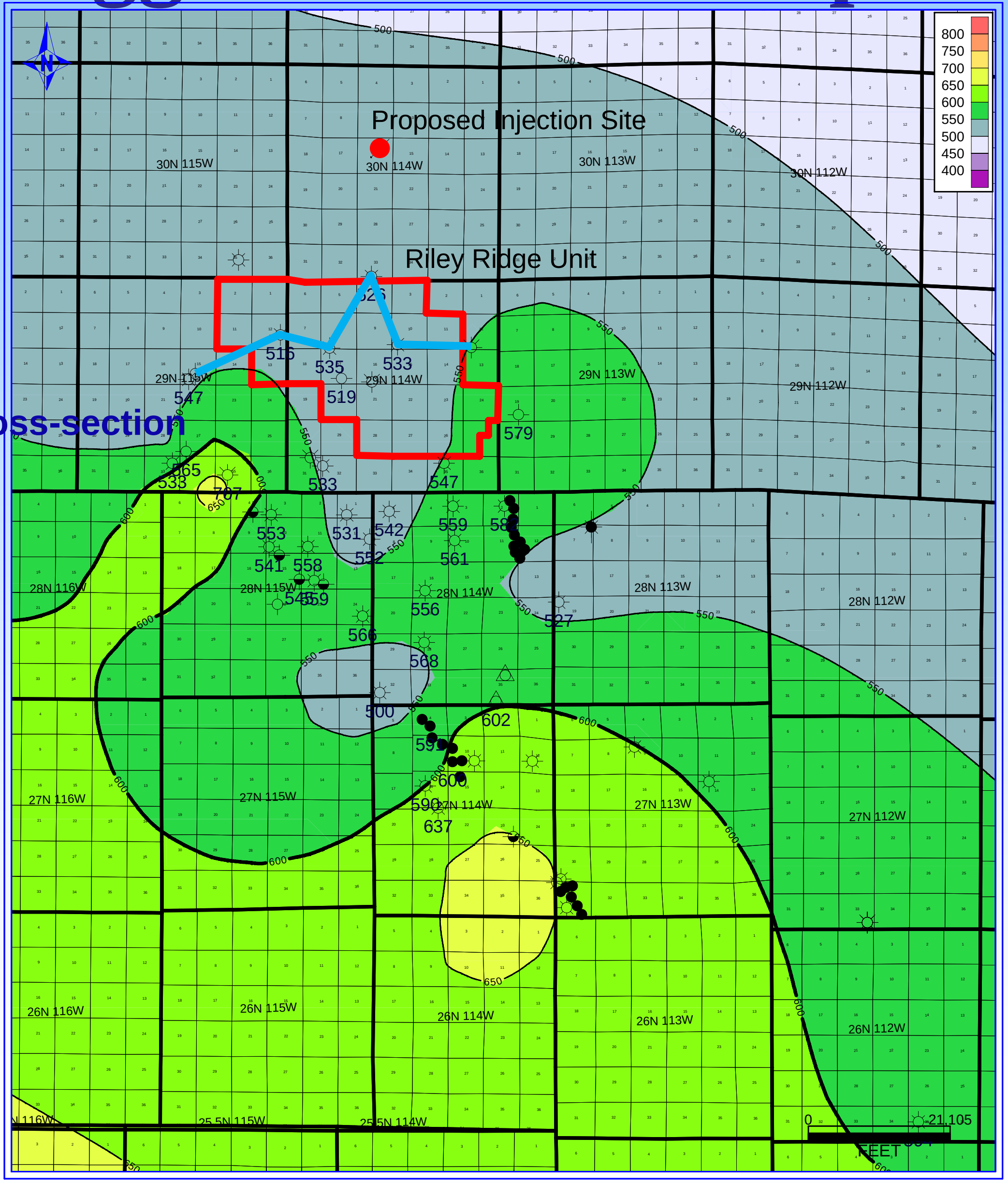
Nugget Sandstone Isopach



Line of Stratigraphic Cross-section

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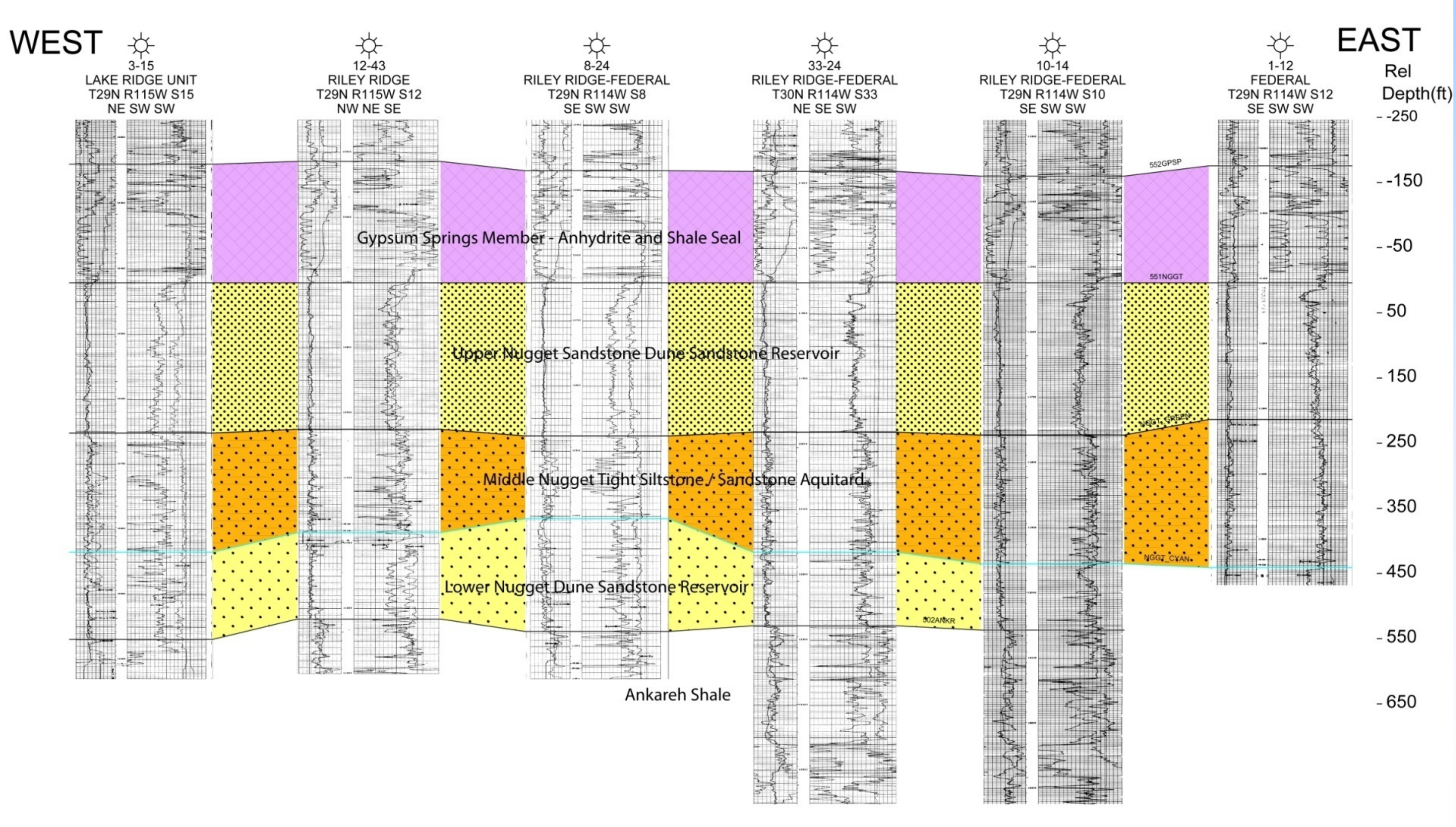
East West Stratigraphic Cross-section, Riley Ridge Unit



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Upper Nugget Core

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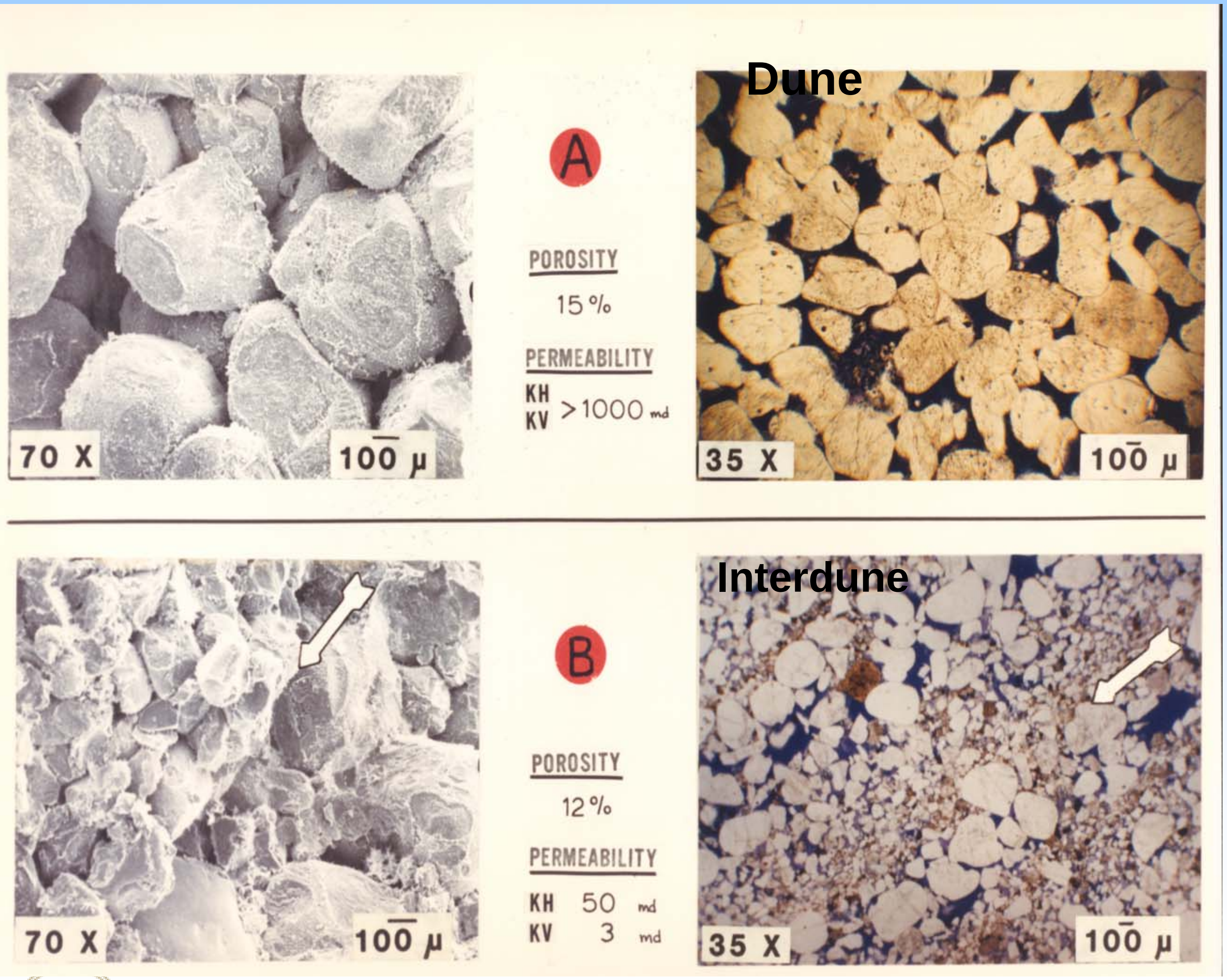
Nugget photomicrographs



Stacked Interdune Deposits of the Middle Nugget: Ripple Laminated Fine-Grained Sandstones and Siltstones

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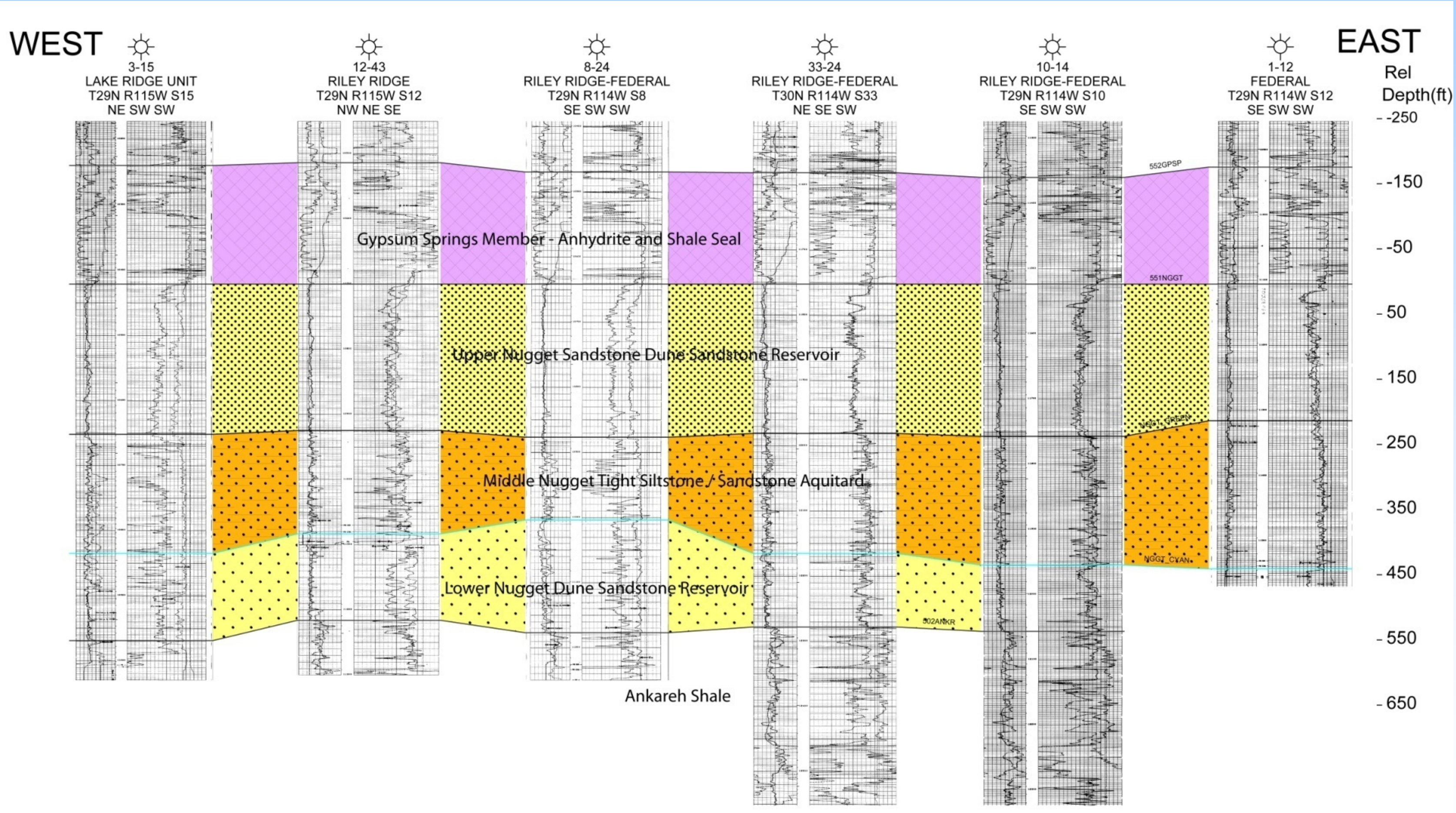
East West Stratigraphic Cross-section, Riley Ridge Unit



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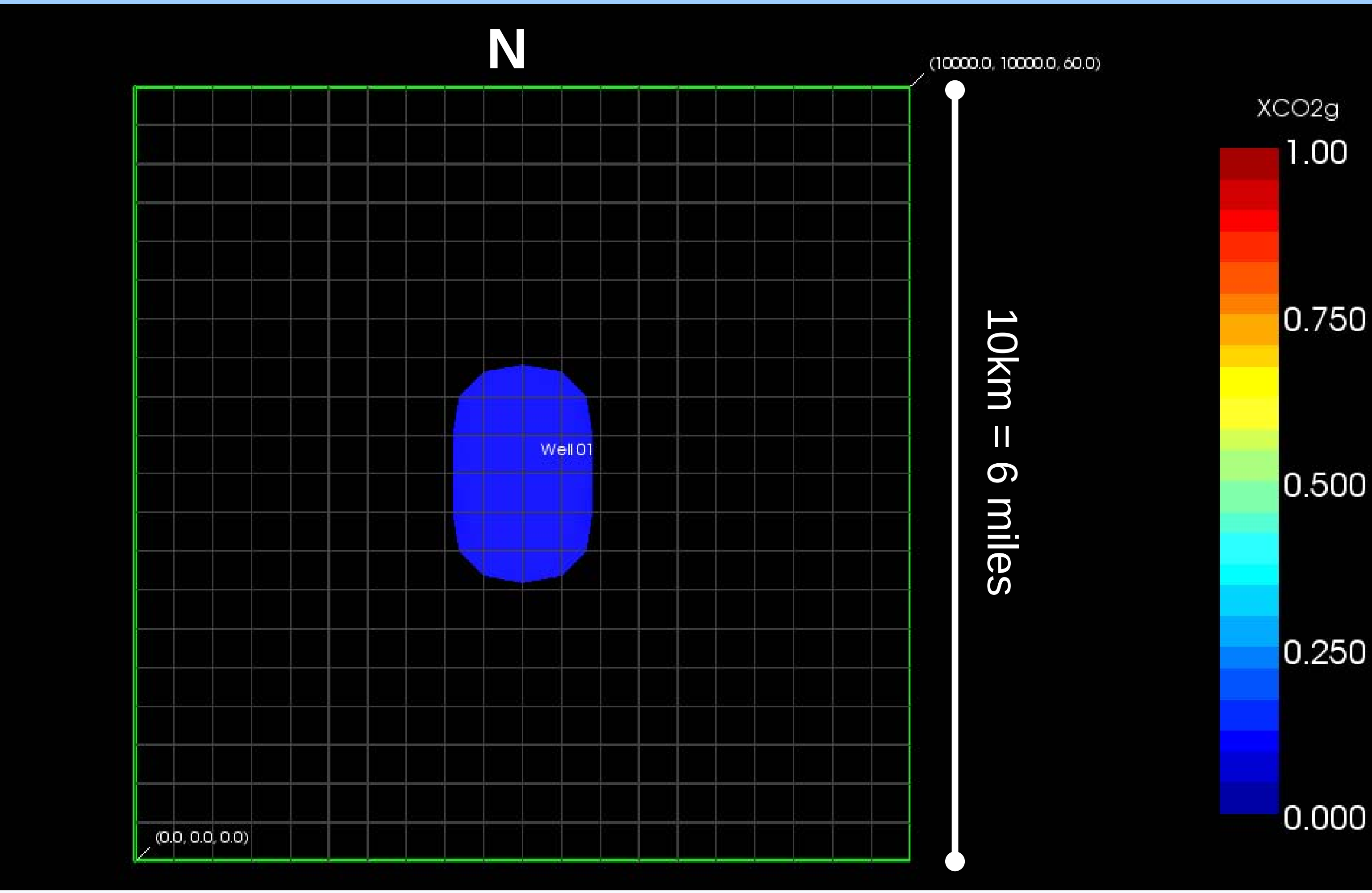
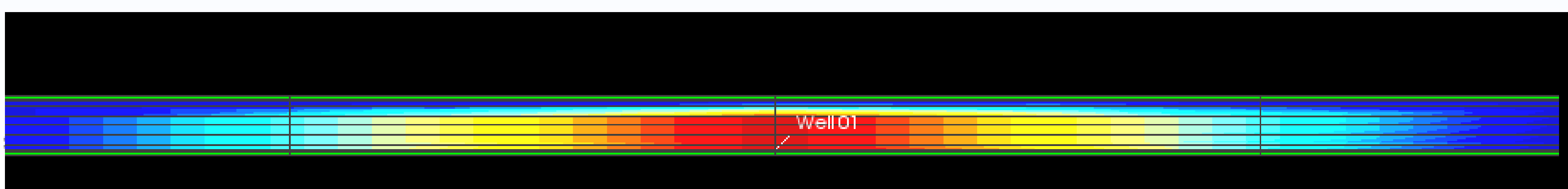
Simulation Parameters

- Simulation area is 10 x 10km
- Nugget is 180 feet thick (6 layers) with top and bottom no flow boundaries.
- Two “rock types”.
- Lower Nugget is lower permeabilities (50-100mD) with anisotropy ratio of 2 (y=2x).
- Upper Nugget is higher perm (150-300mD) with anisotropy ratio of 2 (y=2x).
- x direction represents W-E, y represents N-S.
- One million tons per year injected for three years
- No dip used for calculations

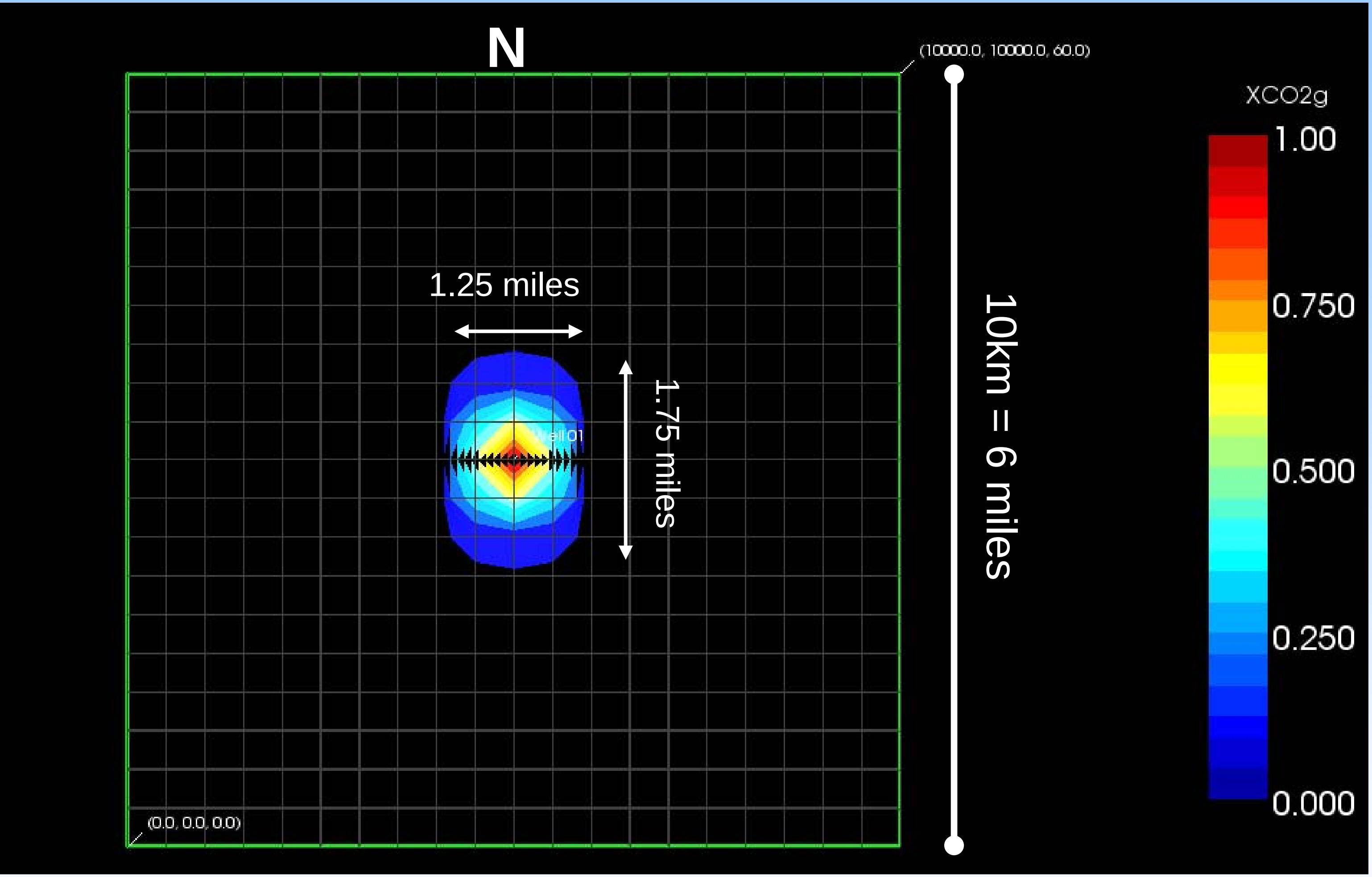
4 months after stop of injection

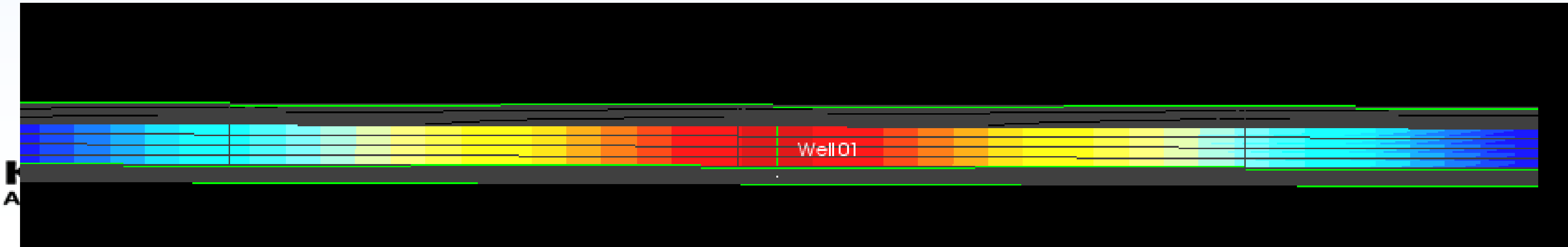


Cross sections are W-E

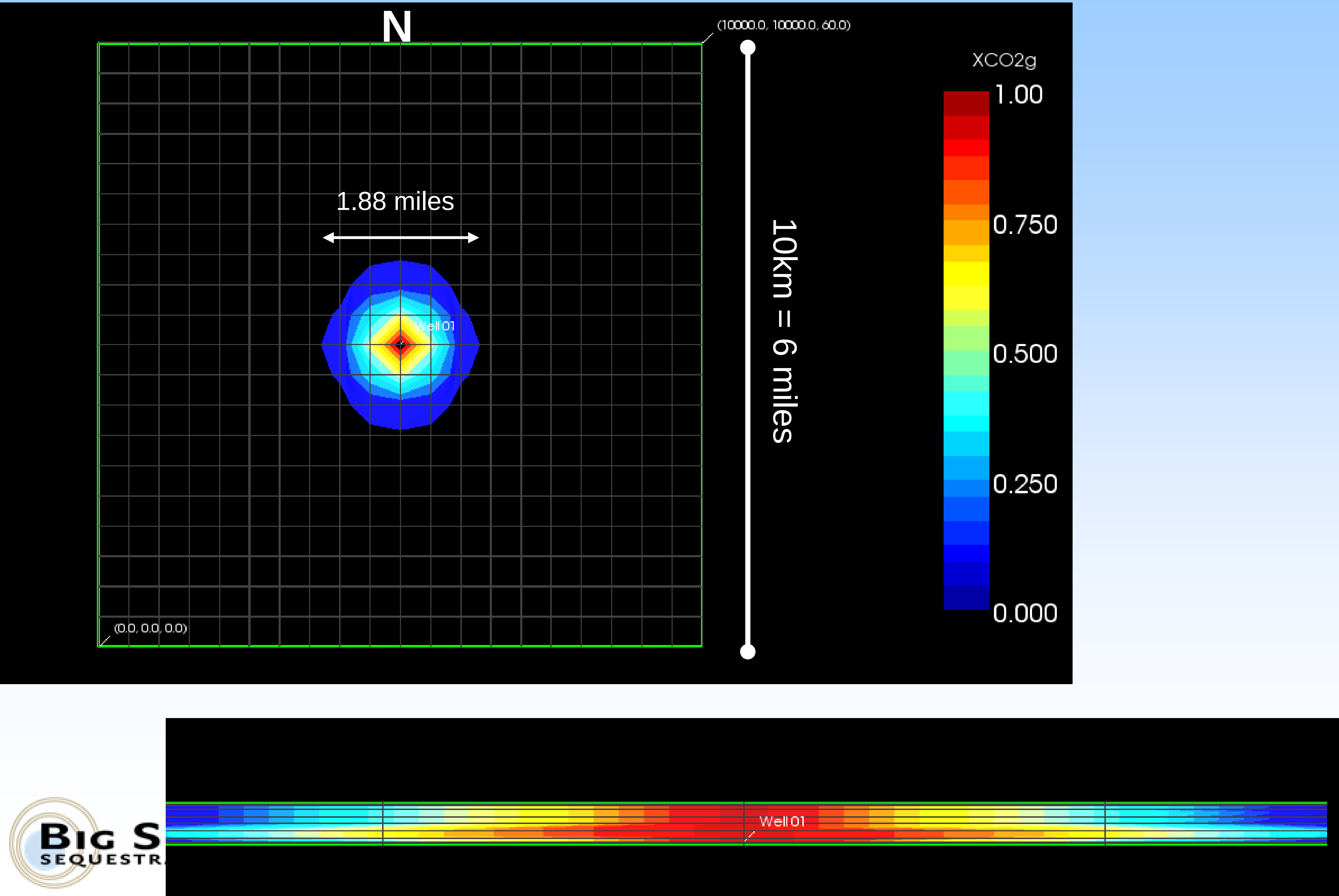


12 years after starting injection





100 years after starting injection



Phase III Large Volume Demonstration Project Timeline 2008-2016

The planned Key Project Dates are:

- Baseline work completed by the end of 2010
- Drilling operation begins by mid 2010
- Injection operation begins in 2011
- MMV Events occur from 2010-2016
- Injection Operations end in 2013-14
- Site Closure complete by 2016

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Unique Characteristics of the Phase III project

- This project will be able to test our current MMV technology on a much deeper target (~11,000 ft) than current projects. For comparison, the Sleipner, Weyburn and In Salah are sequestering and monitoring CO_2 injection at depths of 3300, 4950, 6000 feet respectively.
- Project will also test the potential of similar formations that are regionally significant in both the BSCSP region and the southwest (Navajo, Weber)
- Actual volumes of CO_2 to be injected are approaching commercial scales (up to 1,000,000 tonnes / year)
- The LaBarge Platform is currently being evaluated as a commercial sequestration site
- Project will provide an opportunity to test new regulatory frameworks for CCS and ownership of geologic pore space

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BSCSP Regional Characterization Efforts

- Build upon existing GIS framework to support technical decision making, project operations, and public outreach and education.
- Manage and incorporate data from the large volume injection test and basalt pilot into geospatial databases, static maps and interactive mapping tools.
- Integration of diverse data within existing geodatabases, and the analysis, enhancement, visualization, interpretation, and dissemination of these data to project scientists, managers, decision makers, stakeholders, and the general public.
- Assemble a regional database that will aid in development of commercial scale projects in southwestern Wyoming and geologic analogues across the region.
- Complementing and augmenting national data sets and the National Carbon Atlas
- Provide updated data, including revised capacity estimates, emissions, and delineation of relevant sinks as directed by the GIS working group and NETL

Project Significance to the Region

- The Nugget Sandstone is projected to be able to store in excess of 10GT, about 100 years of current Wyoming carbon dioxide emissions from power plants.

- Nugget is similar to other regional saline aquifers being considered as sequestration targets including the Tensleep, Weber, and Navajo formations that could be used for storage of regional emissions.

- This area has access to the state-wide CO_2 pipeline infrastructure.

- This project will provide the basis for a rigorous economic evaluation of deep sequestration and provide critical information to determine if commercialization is viable in the area.

- Additionally, the nearby Rock Springs uplift is estimated to have a storage capacity of 26GT that will supplement the Moxa storage.

Economic Feasibility Modeling and Analysis

Objectives

•Establish economic model framework for CCS that incorporates the relationship between source and sink and 5 sequestration practices (EOR, ECBM, depleted oil and gas reservoirs, deep saline aquifers and mafic rocks)

•Conduct an economic analysis of geologic sequestration potential for different geologic systems including basalts, saline formations, and unmineable coal beds.

Strategy

•Identify main regional sources and sinks

•Quantify quantities and costs

- Capture for electric power plants
- Transport from source to sink
- Injection

•Integrate to obtain feasible CCS options

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Phase III Project Infrastructure Requirements

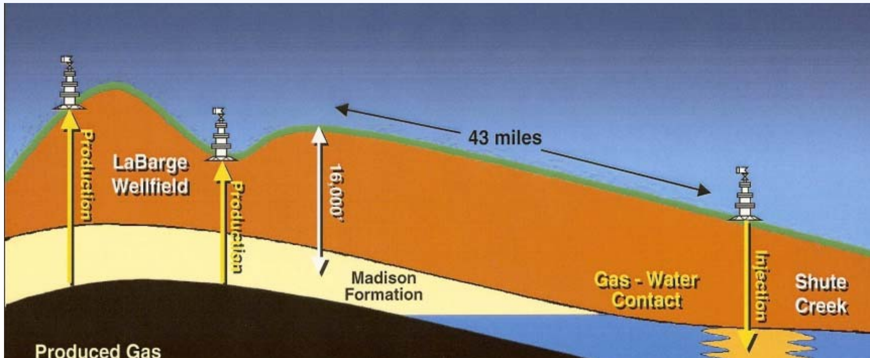
CO_2: Cimarex Energy will supply CO_2 from their gas plant (completed by 2009). The plant will extract methane and helium from the Madison limestone formation at ~18,000 feet.

Pipeline: BSCSP will construct short (<0.5 mile) lateral pipeline originating from Cimarex's CO_2 trunk line that will transport the CO_2 to the injection well on WY State Trust lands

Compression: Preliminary estimates suggest some on site compression may be necessary. If needed, Schlumberger will operate compression and injection activities

Injection Wells: 1 injection well will be drilled by BSCSP and completed by Schlumberger. Instrumentation for data acquisition will be conducted by Schlumberger.

Monitoring Wells: 2 monitoring wells will be drilled and completed by Schlumberger. Instrumentation and operation for data acquisition for MMV and modeling will be conducted by Schlumberger.



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Regulatory Permitting Requirements

The BSCSP will begin conducting permitting operations upon notification of award; the table outlines the necessary permits, responsible agencies and time needed.

Permitting Activity	Responsible Agency	Time Requirements (days)
File Application for Permit to Drill (APD)	Bureau of Land Management (BLM)	120
File APD	Wyoming Oil and Gas Compact Commission	120
Drilling Plan	BLM	180
SUPO	BLM	180
On Site Visit		30
Cultural Survey	State Historic Preservation Office (SHPO)	120-240
Threatened and Endangered Species Survey	United States Fish and Wildlife Service (USFWS) or Wyoming Game and Fish Department (WGFD)	120 -240
UIC Application		
Class V Well	Wyoming Department of Environmental Quality (WDEQ)	120-180
Class II Well	WOGCC	120
Water Rights	Wyoming State Engineer	5 days – investigation only as a water right is not expected
Temporary Use Permit (operations on state lands if needed)	Wyoming State Land Board (WSLB)	60
NEPA – Categorical Exclusion (CX) or Environmental Assessment (EA)	BLM	365
Record of Decision (ROD)	BLM	180-365
Stipulations	BLM, WGFD, Surface Owner	90

Planned Public Outreach and Education

In communities near the large scale injection the Partnership will hold regular public forums, roundtable discussions, and distribute factsheets, newsletters, and other outreach material to inform stakeholders of the:

- Project planning process
- Goals of projects
- Technical details of projects
- Project operations and timelines
- Roles of Partnership staff and members in project

Other activities

-Required regulatory public hearings

- Information will be distributed on the Partnership web site

- The Partnership will generate frequent press releases to keep the media and the public informed of partnership activities

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Potential Barriers and Strategies for Success

Potential Barrier	Mitigation Strategy
Mixed surface and mineral ownership	Limit activities to state lands
Ownership of pore space	Negotiate with private surface owners for temporary leasing of pore space
Plume will extend to areas of Federal mineral ownership	EIS
Presence of H2S in the CO2 strea	Adoption of acid-gas handling protocols and siting of infrastructure to avoid potential impacts
Lack of carbon sequestration regulatory framework	State of Wyoming will adopt carbon sequestration regulatory framework in 2009

Phase III MMV Plan

1. Obtain preliminary data feeds from CO_2-PENS site-specific model.
2. Obtain preliminary data feeds from site-specific process models (reservoir, atmospheric, etc.)
3. Develop detailed MMV plan that will include:
   - Measurement parameters, metrics and frequency of events
   - Definition of compromising activities
   - Identification of the types and positions of test equipment and specifications
   - Specifications for timing of activities
4. Develop data visualization and analysis methods to support MMV data collection, interpretation, and storage.
5. Determine pre-injection background conditions.
6. Advise data collection and conduct data analysis on processed data.
7. Perform isotope and colloid analysis on sample aliquots.
8. Determine short and long-term impact on reservoir rock properties and water quality.
9. Produce final report on MMV methods effectiveness and transferability to other locations

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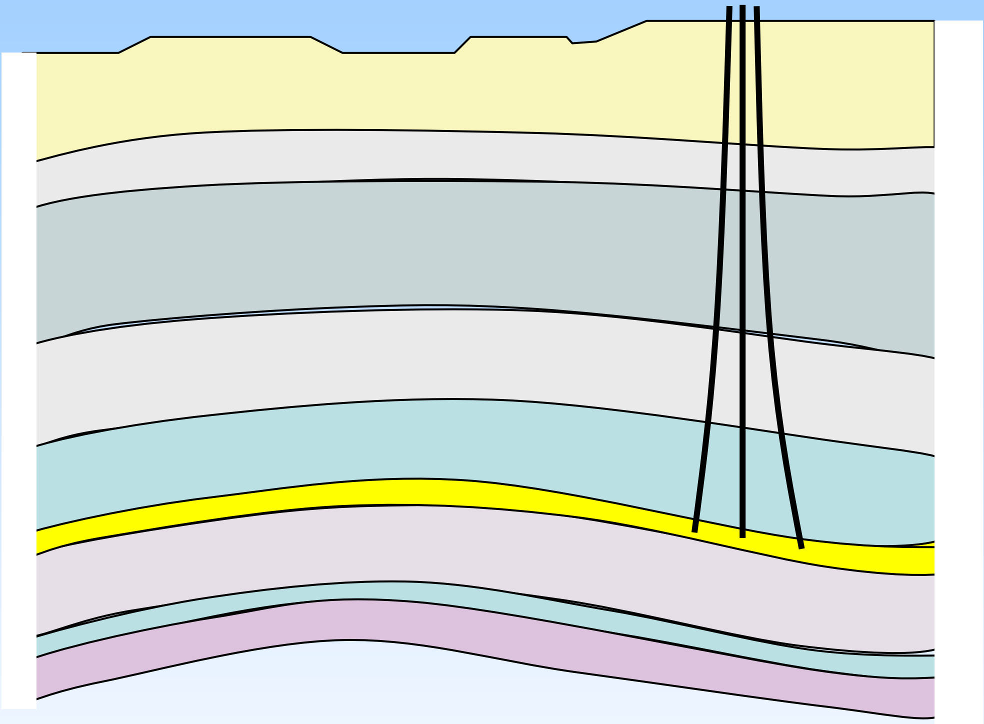
Phase III MMV



- One injection well, Two monitoring wells
- All same drill pad, two of the wells will be deviated
- Real-time down hole P & T sensors
- Fluid sampling for geochemical studies
- VSP
- Surface sensors (CO2 & H2S)

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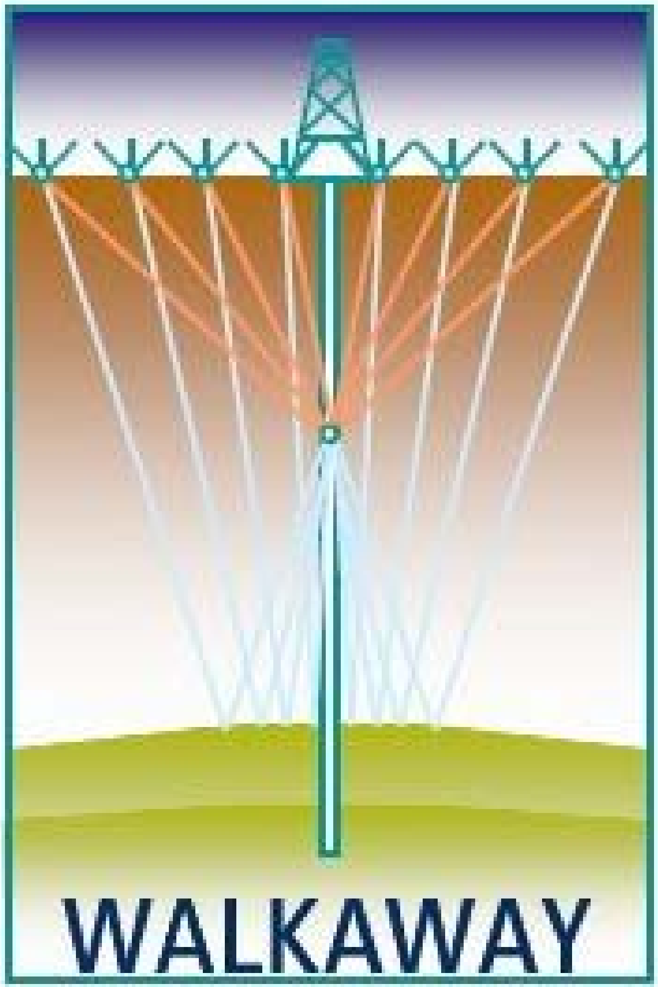
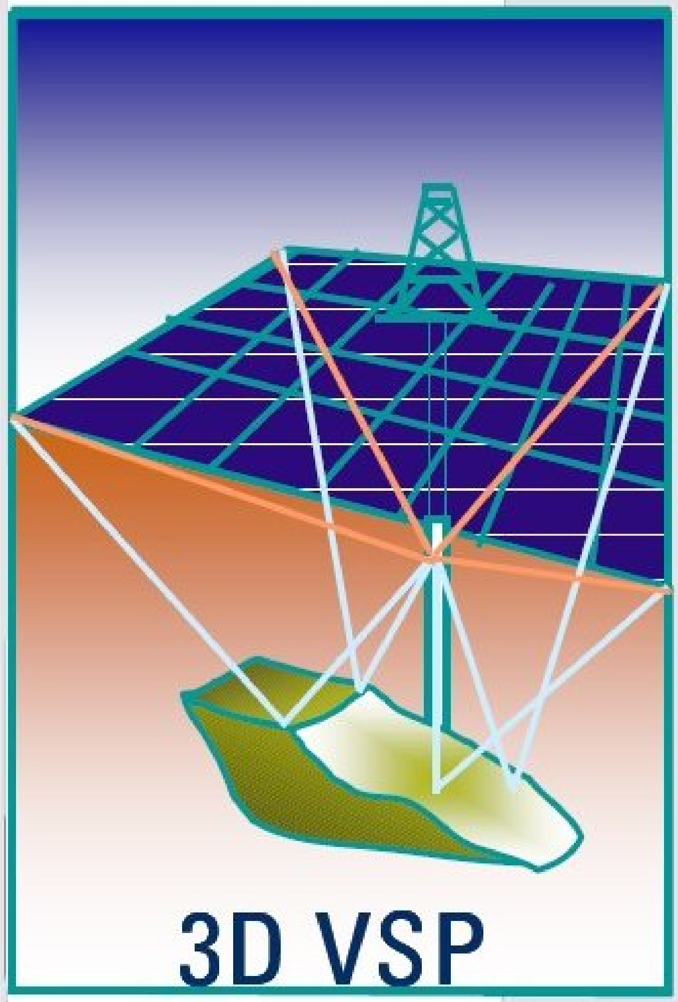
VSP Surveys: Walkaway & 3D VSPs



- **Results in high resolution images around a well**
- **Has a smaller acquisition footprint that surface seismic data**



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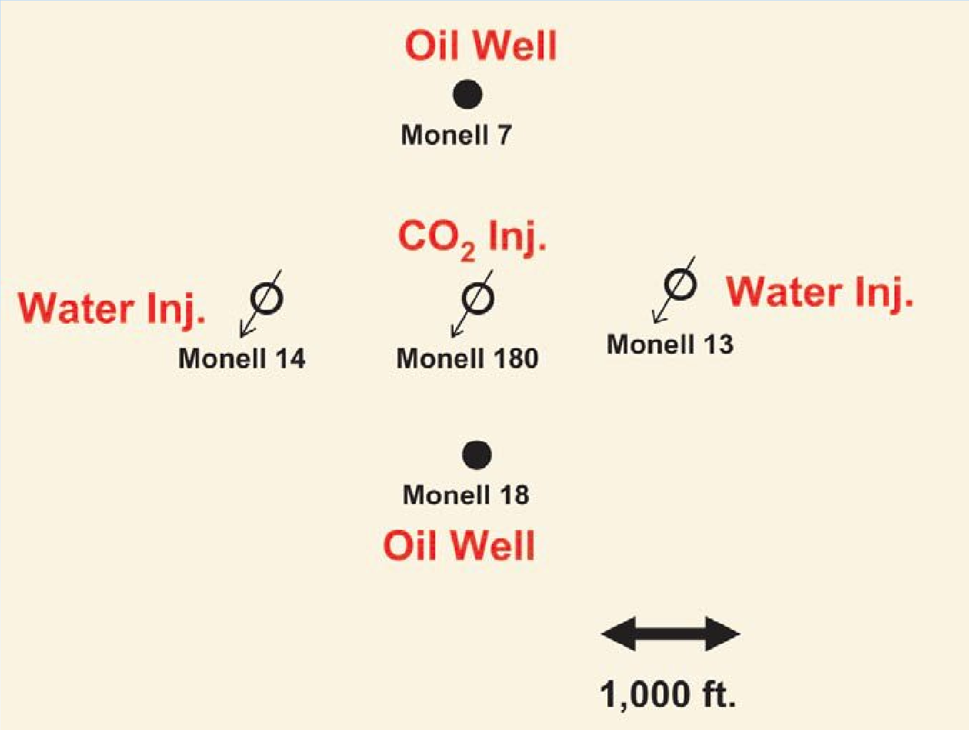
Examples: Anadarko Time-lapse 3D VSP

- CO_2 EOR Pilot in a homogeneous sandstone unit
- Pilot used a 5 spot pattern
- Injected 430 million ft^3 of CO_2 over 18 months
- Used 80 geophone levels & 1007 source points in 3D VSP



(O'Brien et al., 2004)

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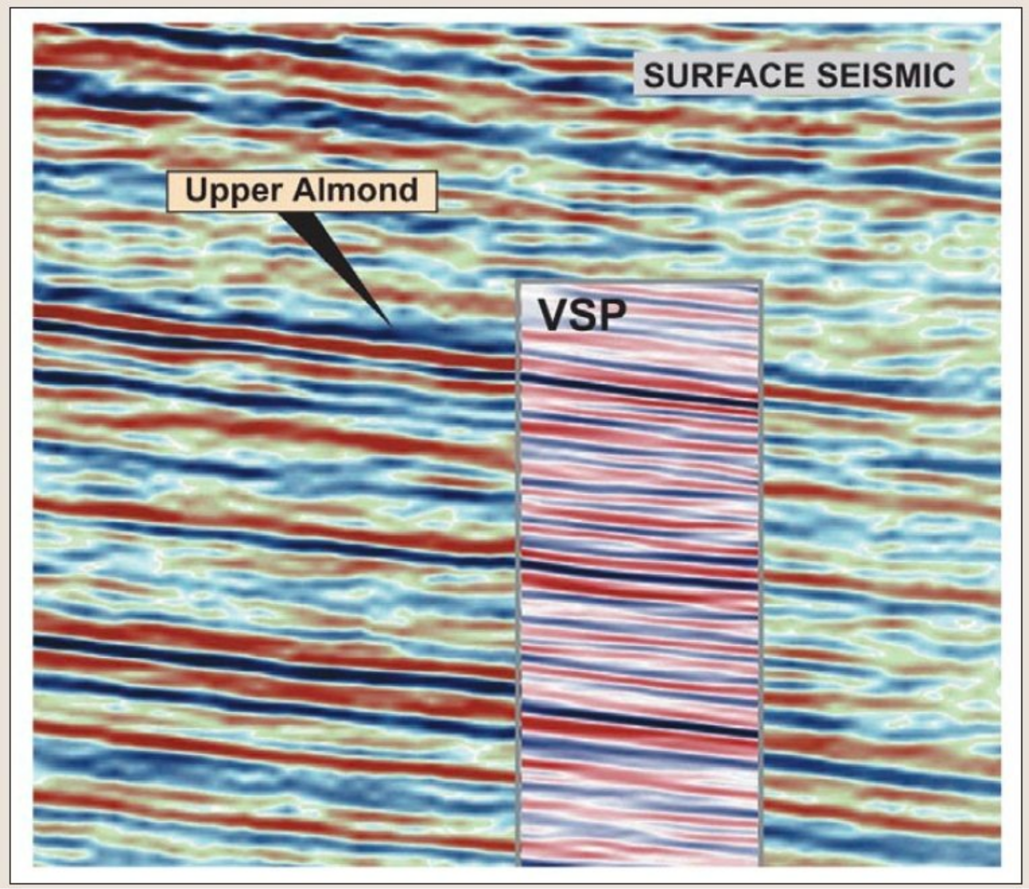
Examples: Anadarko Time-lapse 3D VSP

- **Higher resolution data was used to map stratigraphic variations in area**
  - **Vertical resolution in zone of interest was 80 ft**
- **Higher signal-to-noise ratio and repeatability allowed for more detailed time-lapse monitoring**



(O'Brien et al., 2004)

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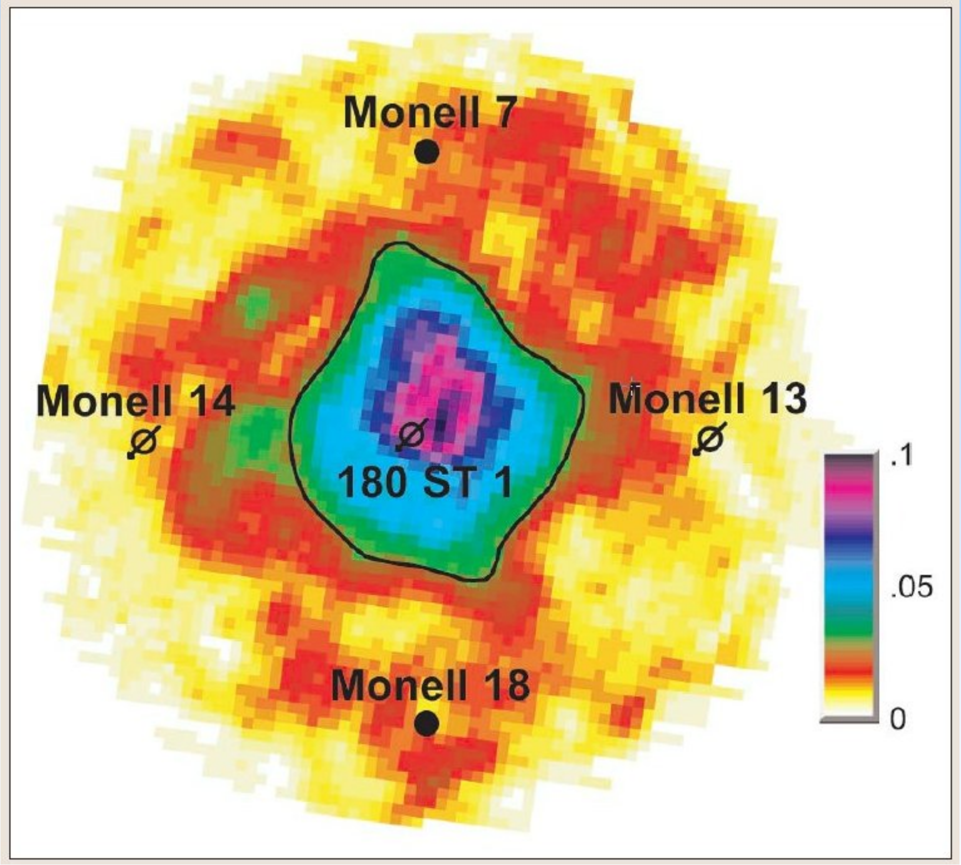
Examples: Anadarko Time-lapse 3D VSP

- **Clear amplitude anomaly associated with the CO_2 flood**
  - **Indicates that the CO_2 has migrated 700 – 900 ft away from the injector well**
- **Decrease in P-wave velocity was between 14-19%**
  - **Uncertainties in pore fluid properties or short comings in modeling equations**



(O'Brien et al., 2004)

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MMV – Well Logging

- Sonic, density, neutron, NMR and the various induction and resistivity logs are potentially suitable for our site
- The Reservoir Saturation Tool (RST), a through-casing pulsed neutron tool designed to measure water and hydrocarbon saturations, is well suited to CO_2 monitoring. Work at Frio (Muller et al.) has demonstrated successful CO_2 saturation logging with the RST tool.

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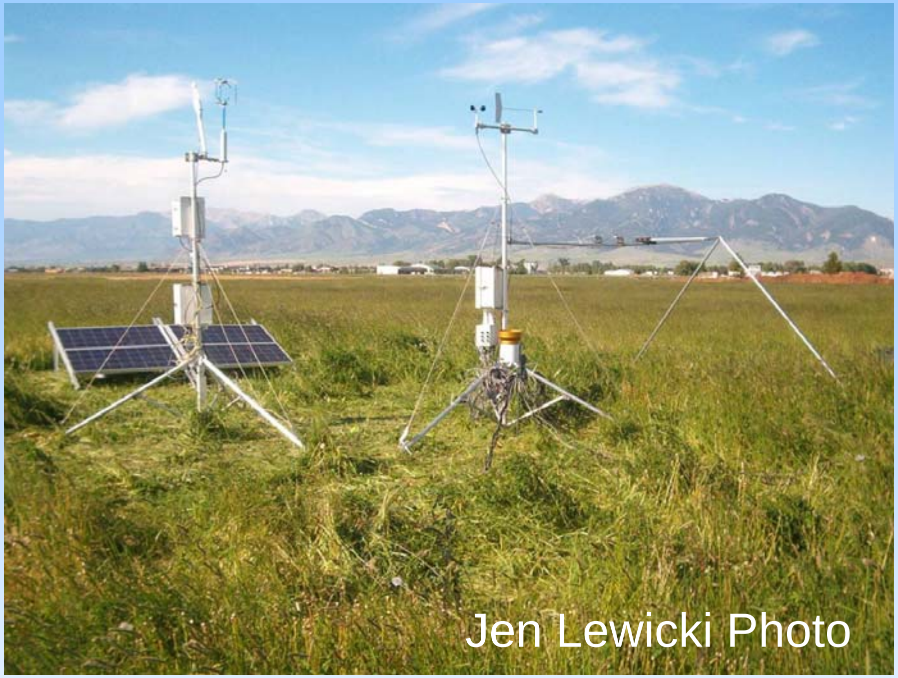
MMV – Near Surface

- Soil Flux Chambers
- Eddy Covariance
- LIDAR
- H_2S Monitoring



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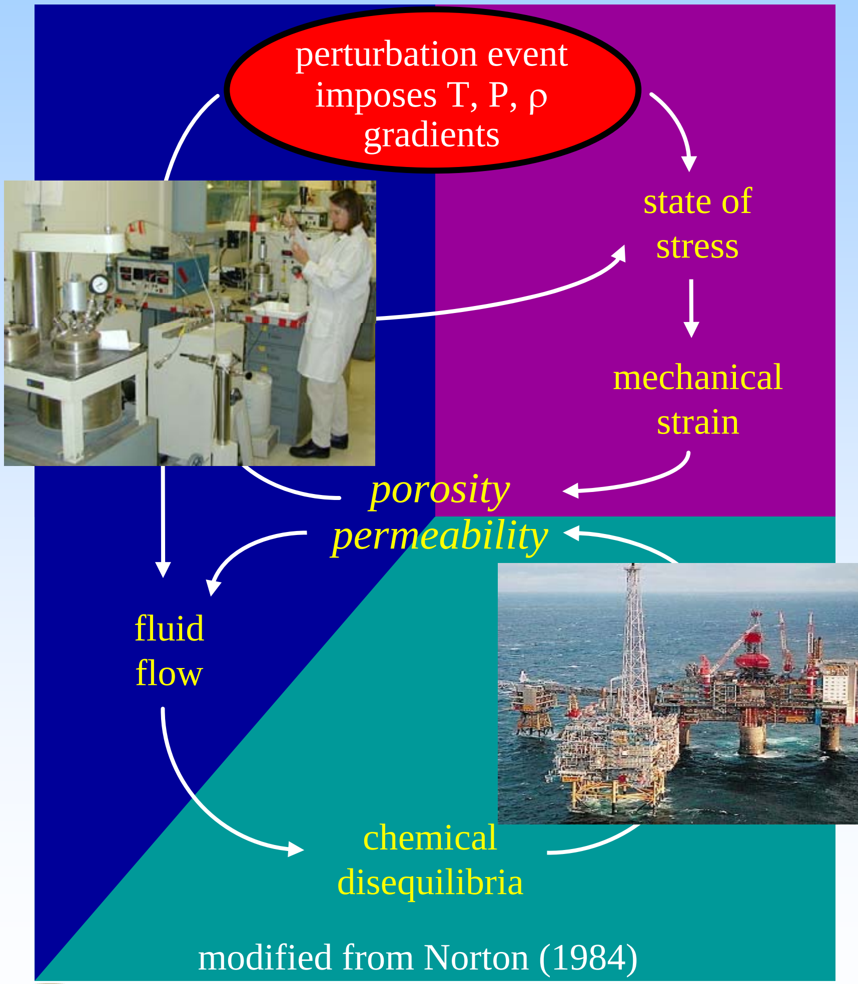
Phase III Modeling

Modeling activities will include:

- Containment simulations such as brine and mineralization reactive-transport modeling of the plume migration both during injection and post-injection
- Cap-rock fracture static and dynamic modeling
- Geomechanical modeling of fault-failure envelopes
- Simulation of torpid releases of CO2 from the proposed BSCSP site including slow seepage from wells, faults, and broad vadose zone transmission
- Simulation of induced seismicity and microseismicity

- International modeling team involvement

Modeling the integrated processes & isolation performance of geologic CO_2 storage



- LLNL's simulation package
  - ✓ NUFT (Nitao)
  - ✓ GEMBOCHS (Johnson)
  - ✓ LDEC (Morris)
  - ✓ TProGS (Carle)
- Relevant perturbations
  - ✓ CO_2 disposal in saline aquifers
  - ✓ CO_2-flood EOR & sequestration
- Process coupling controls
  - ✓ Sequestration partitioning among distinct trapping mechs per coupled multiphase flow & geochem processes (Johnson et al., 2002, 2004b)
  - ✓ Evolution of seal integrity per coupled geochem & geomech processes (Johnson et al., 2003, 2004a, 2005)

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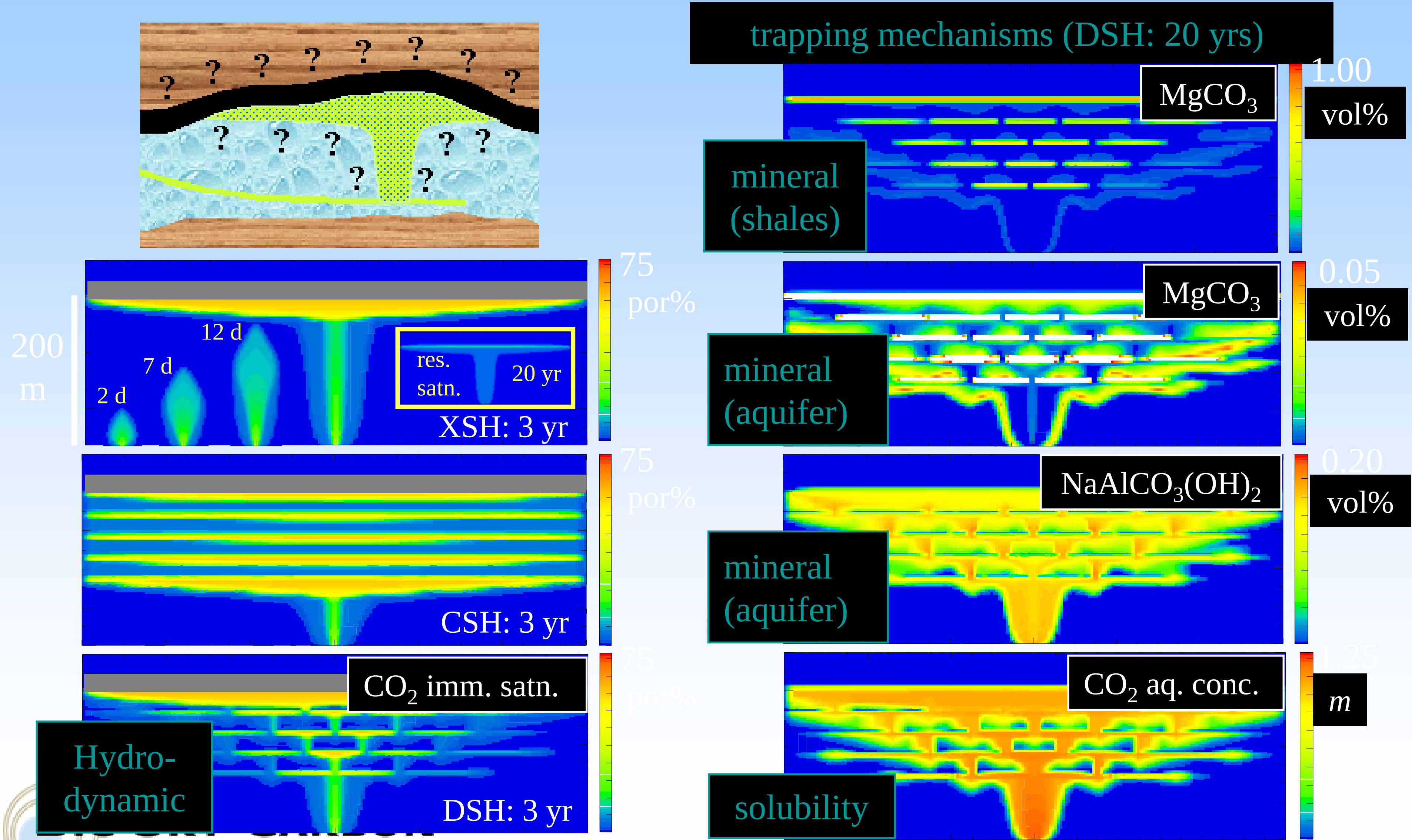
Reactive transport models simulate partitioning of storage mechanisms (Johnson et al., 2002, 2004b)



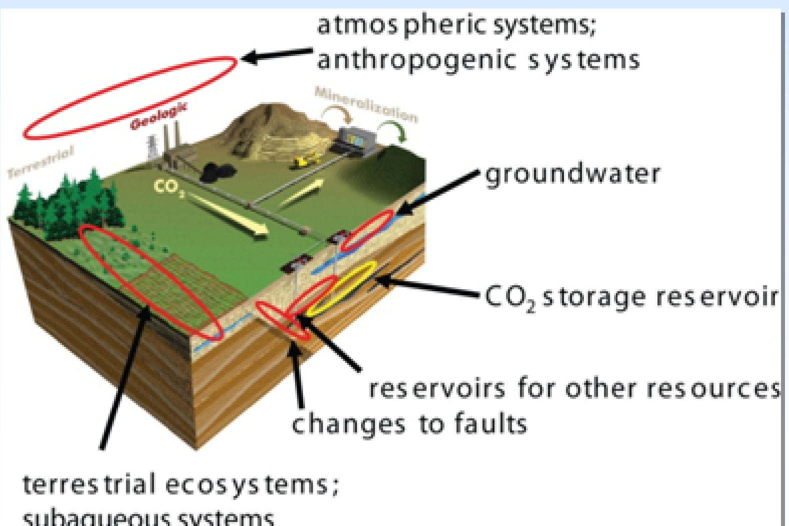
SEQUESTRATION PARTNERSHIP

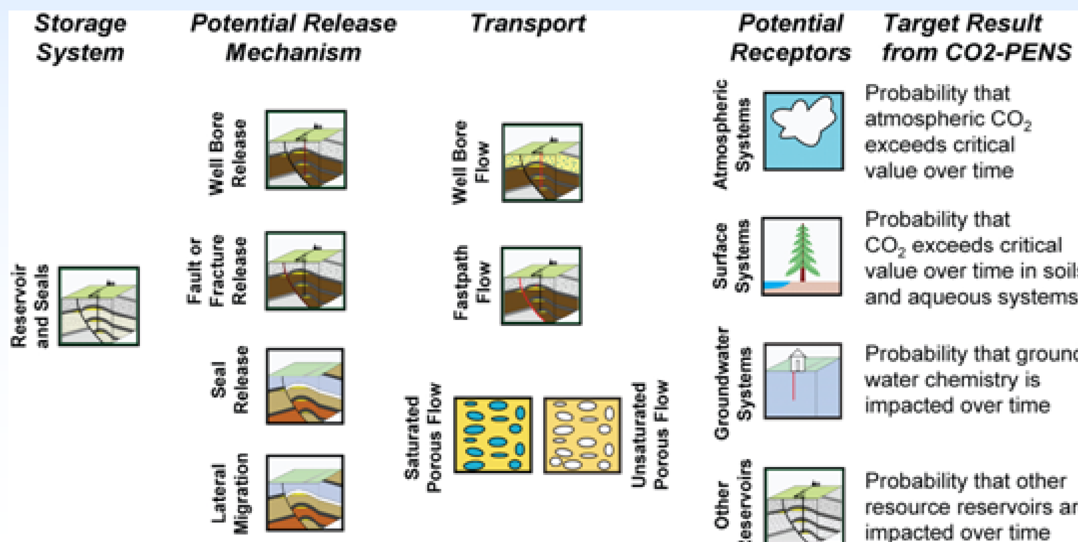
Risk Assessment and Mitigation Strategy

This component will be performed by LANL and LLNL

➢Los Alamos has experience from work in support of DOE's Carbon Sequestration Program, which includes the development of the system level model CO_2-PENS, as well as detailed work on the integrity of wellbores and seals in the context of CO_2 storage

➢Lawrence Livermore National Laboratory will work on containment and integrating monitoring methods





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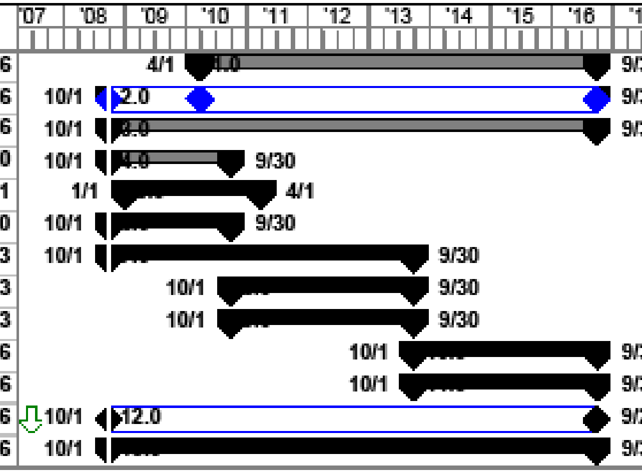
Phase III Large Volume Demonstration Project Accomplishments to date:

- Significant progress has been made on project planning, design and operational management
- Identification of project site location, procurement of CO_2, assessments of existing and needed infrastructure, compilation of relevant research to project, and regional geologic characterization that includes a preliminary static geologic model
- Agreements with major industry partners; Cimarex Energy and Schlumberger
- Geologic modeling and identification of appropriate MMV methodologies
- Letters of commitment have been received from all institutional partners

ID	WBS	Task Name	Start	Finish
1	1.0	Regional Characterization	4/1/10	9/30/16
7	2.0	Public Outreach	10/1/08	9/30/16
19	3.0	Permitting and NEPA Compliance	10/1/08	9/30/16
23	4.0	Site Characterization and Modeling	10/1/08	9/30/10
36	5.0	Well Drilling and Completion	1/1/09	4/1/11
40	6.0	Infrastructure Development	10/1/08	9/30/10
43	7.0	CO2 Procurement	10/1/08	9/30/13
47	8.0	Transportation and Injection Operations	10/1/10	9/30/13
50	9.0	Operational Monitoring and Modeling	10/1/10	9/30/13
57	10.0	Site Closure	10/1/13	9/30/16
60	11.0	Post Injection Monitoring and Modeling	10/1/13	9/30/16
70	12.0	Project Assessment	10/1/08	9/26/16
71	13.0	Project Management	10/1/08	9/30/16



Phase III Gantt Chart

Project: Gantt Chart_090908
Date: 9/19/08

Task	Summary	Split
Task Progress	Rolled Up Task	External Tasks
Critical Task	Rolled Up Critical Task	PTask
Critical Task Progress	Rolled Up Milestone	Task Progress
Milestone	Rolled Up Progress	Critical Task

BIG SKY CARBON SEQUESTRATION PARTNERSHIP

End Point

- The final endpoint of this research is to:
  - demonstrate the successful deployment of commercial scale geologic sequestration in regionally significant saline aquifers
  - Test the efficacy of MMV approaches for geologic sequestration at depths greater than 10,000 feet

- The Phase III project is expected to be completed by 2016

- Total funds for Phase III are expected to be $ 141.5 M ($65.5 M DOE funds)

Acknowledgments

Questions?

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Big Sky Carbon Sequestration Partnership