# Kevin Dome $CO_2$ Storage Demonstration Project



Lee Spangler
Big Sky Carbon Sequestration Partnership


U.S. Department of Energy
National Energy Technology Laboratory
Infrastructure Meeting
November, 2011

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# Presentation Outline

- Large Scale Project Necessities
- Kevin Dome Site Properties
- Project Design Approach
- Project Overview
- Project Specifics

# Large Scale Test - Pragmatic Issues

- **Reasonably large quantity source of $CO_2$**
  - No pure anthropogenic sources available
  - Capture facility costs do not fit budget
  - Commercial $CO_2$ used for EOR - $35- $40 per Tonne – not affordable unless doing EOR
  - Need pre-commercial source that is inexpensive to develop
- A good quality storage reservoir
- Good quality seals
- All in close proximity

# Kevin Dome Project


- Kevin Dome is a naturally occurring $CO_2$ reservoir in north central Montana
- BSCSP is planning to produce 1 million tonnes of $CO_2$ from the dome and then inject it into the Duperow Formation.

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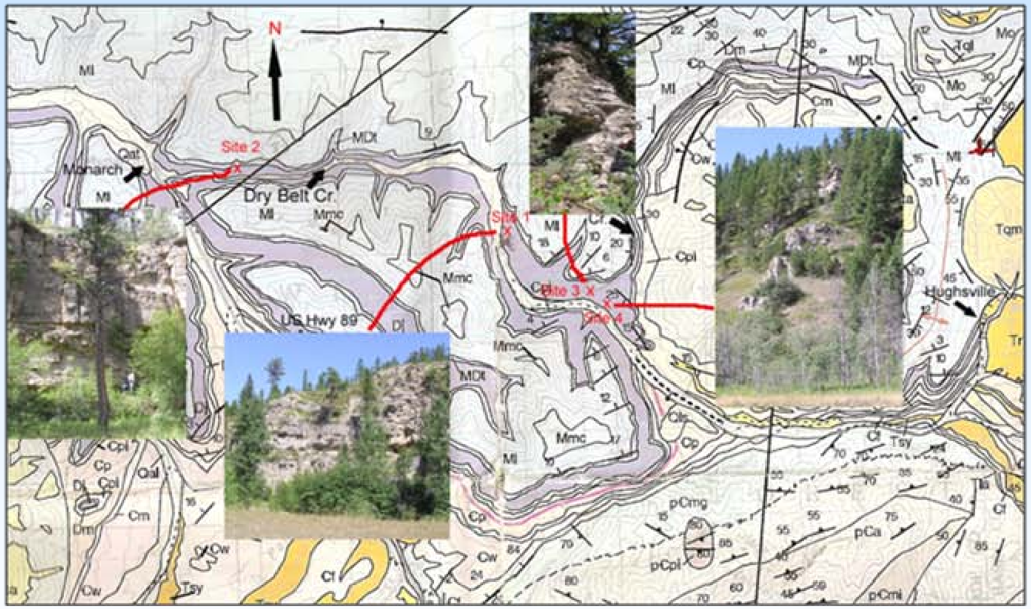
# Outcrop belt of the Devonian Duperow Fm. Near Monarch, Montana (~120 Mi SSE) and locations of measured sections.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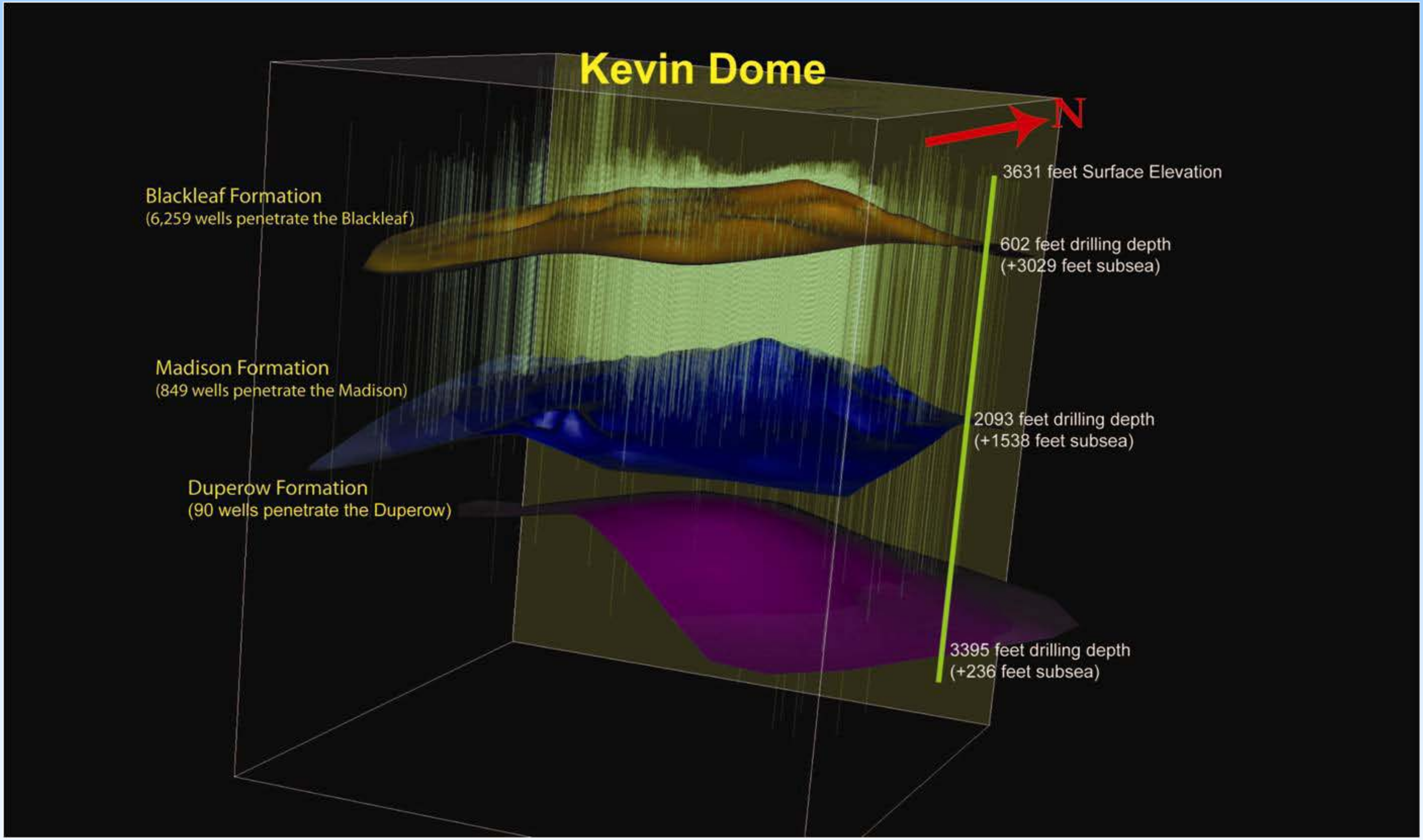
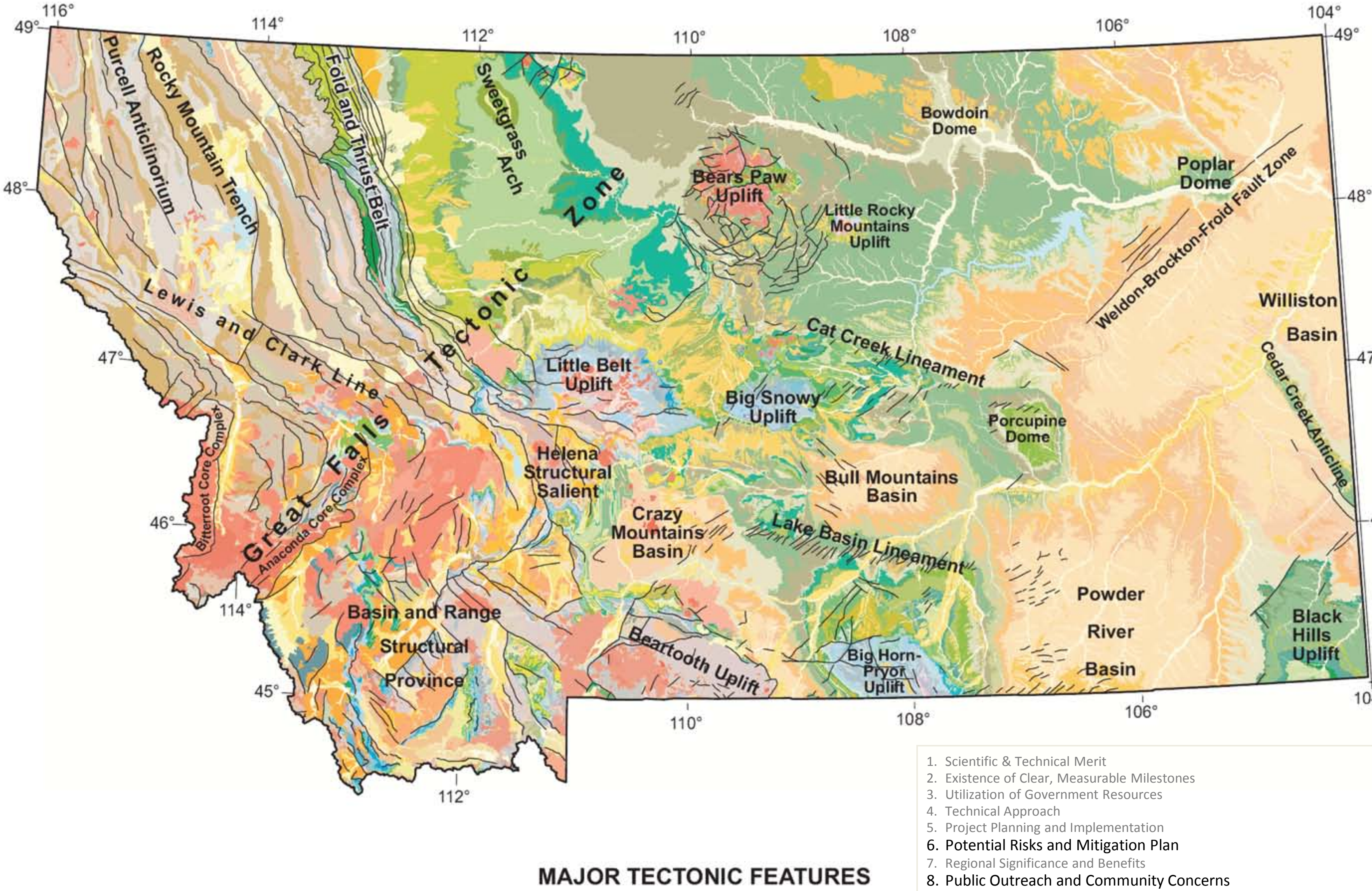
# Kevin Structure Tops & Well Penetrations



# Site Suitability




1. Scientific & Technical Merit
2. Existence of Clear, Measurable Milestones
3. Utilization of Government Resources
4. Technical Approach
5. Project Planning and Implementation
6. Potential Risks and Mitigation Plan
7. Regional Significance and Benefits
8. Public Outreach and Community Concerns

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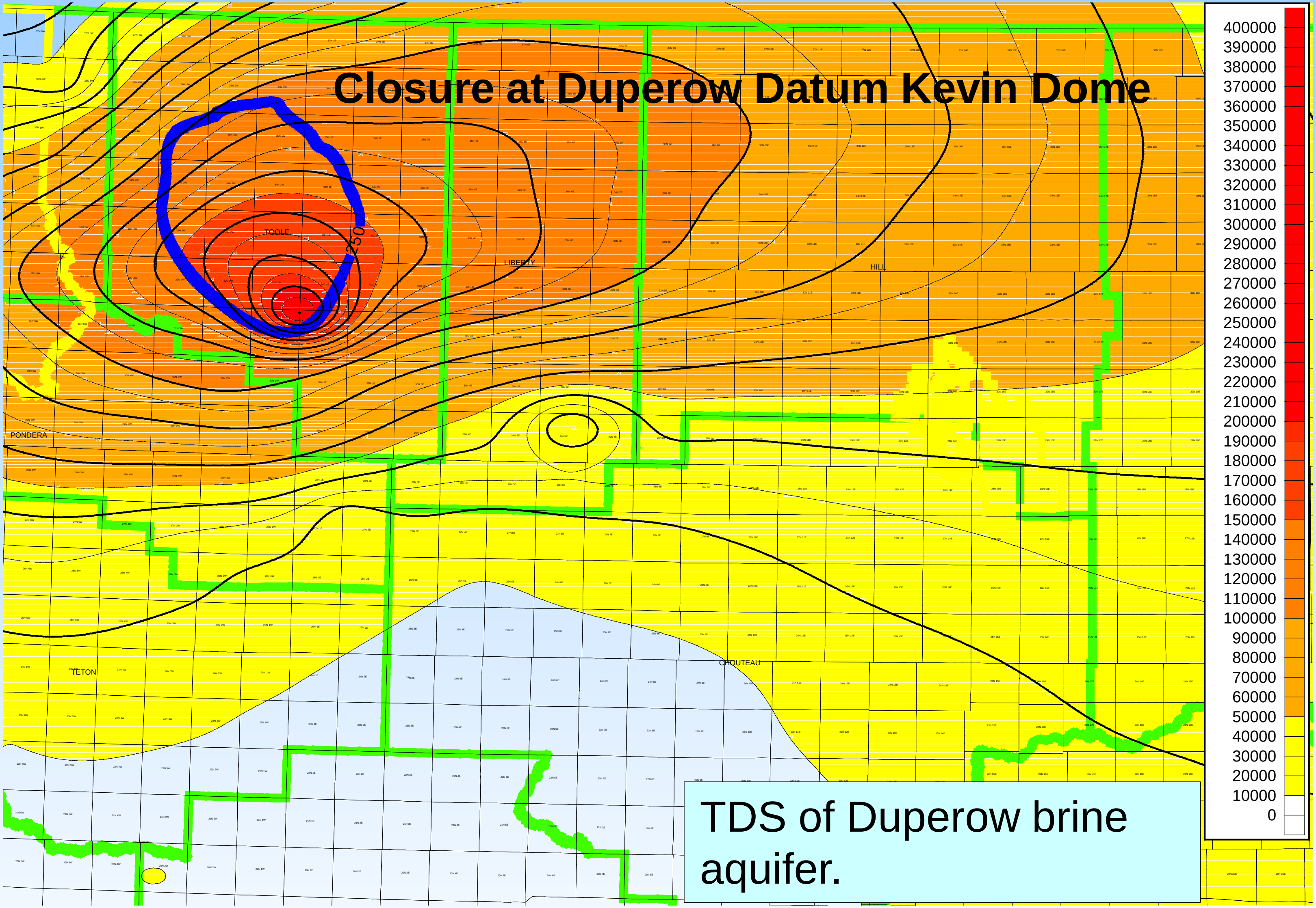
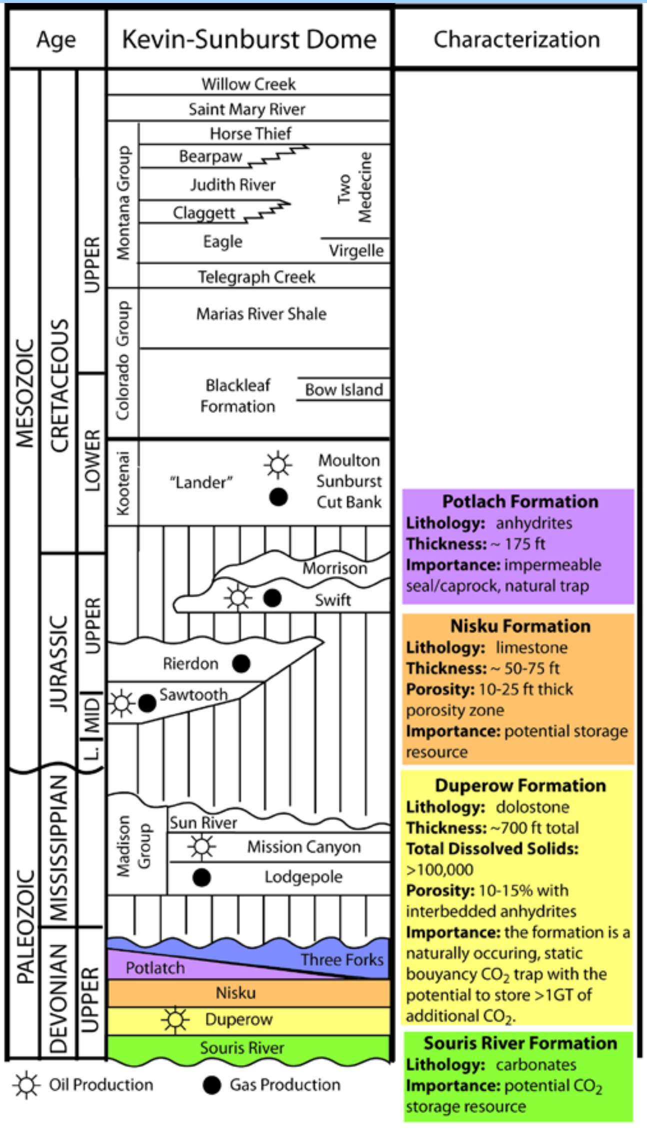
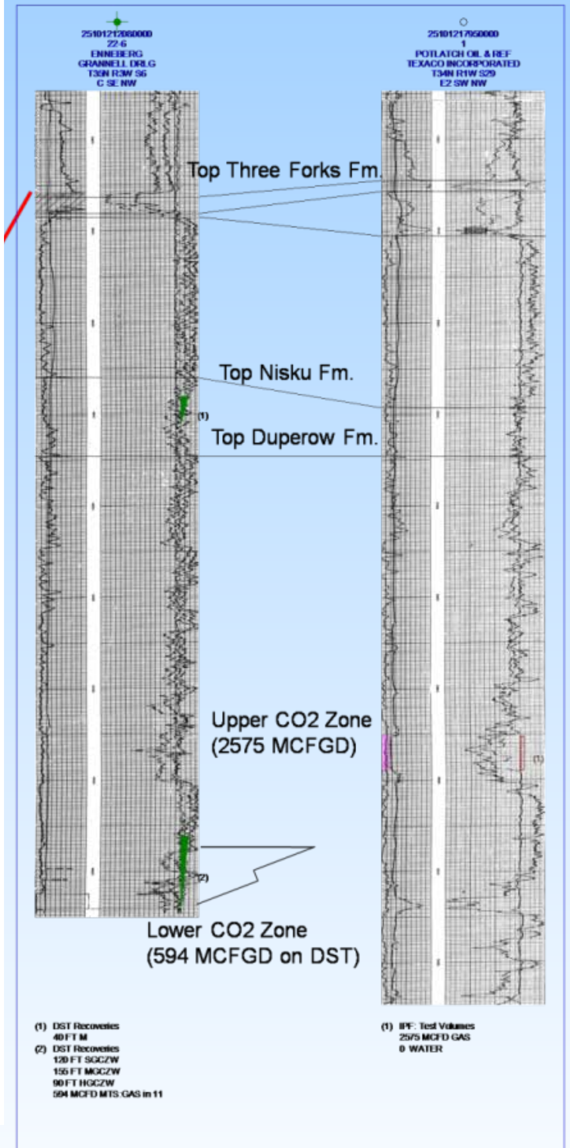
# Site Specific Water Quality



# Stratigraphy




Bakken Sh.
(Regional Seal)

Potlatch Anhydrite
(Regional Seal)

Caprock
Upper Duperow
Anhydrites

100 feet

**Nisku Limestone ~ 50 – 75 ft total thickness with a 10 – 25 ft thick porosity zone**

**Potlach Top**

**~ 175' Anhydrite**

**Nisku Top**

**Duperow Top**

**Upper Duperow ~200' tight carbonates and anhydrites caprock**

**~ 100' Duperow Porosity ($CO_2$)**

**Souris River Top**

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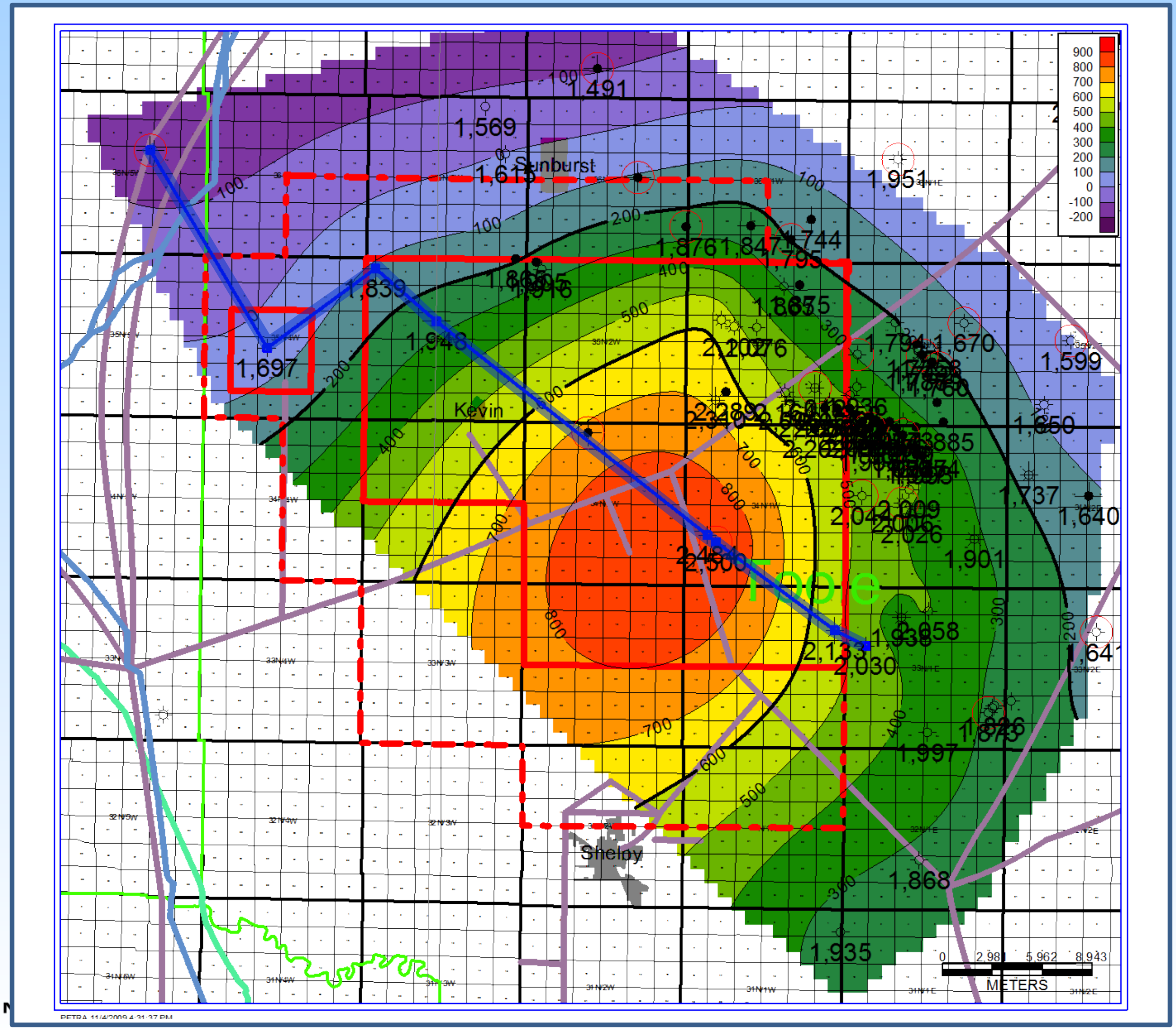
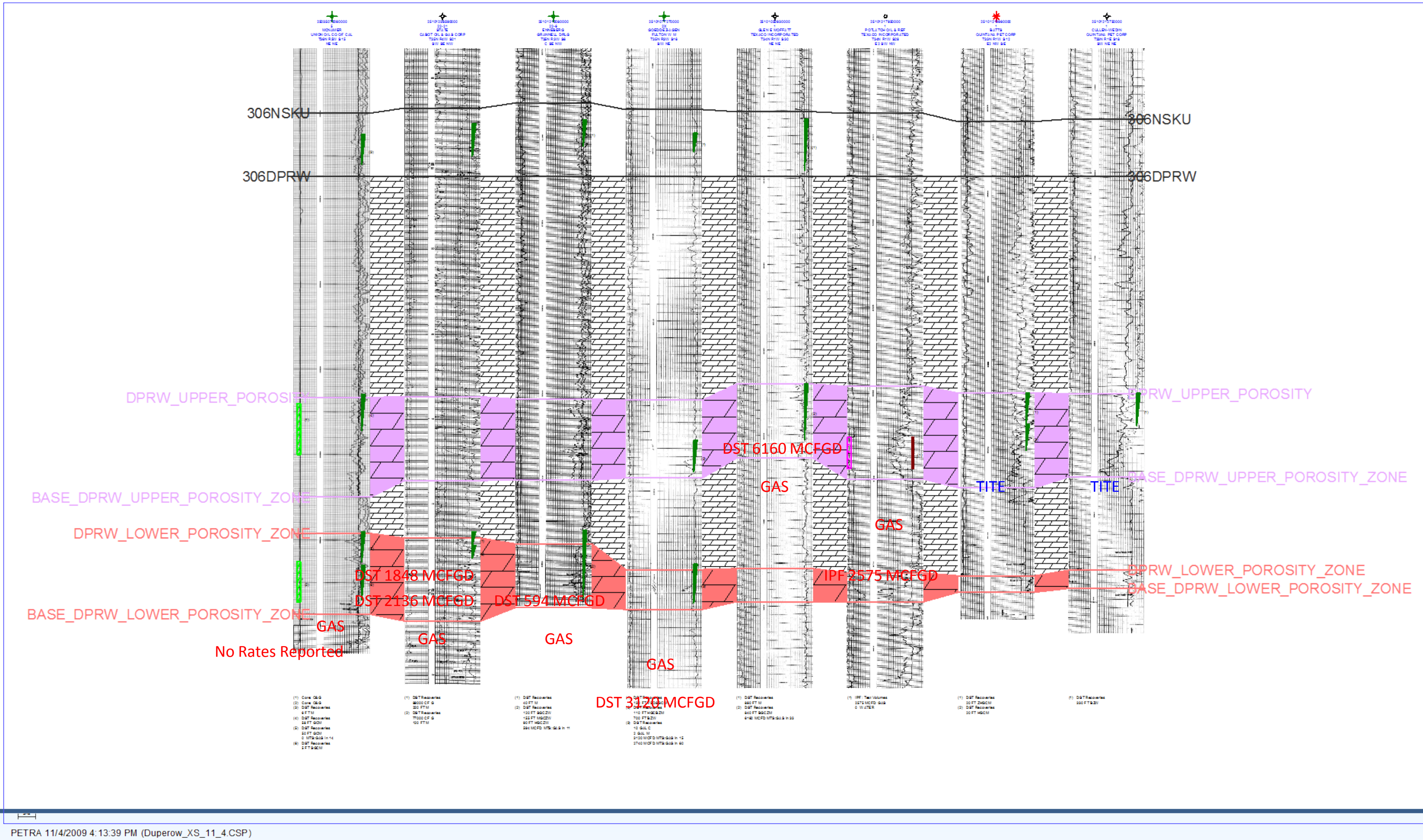
# Structure Top Duperow, Area of Interest Outlines, Pipelines, Line of XS



# NW - SE Cross Section Kevin Dome

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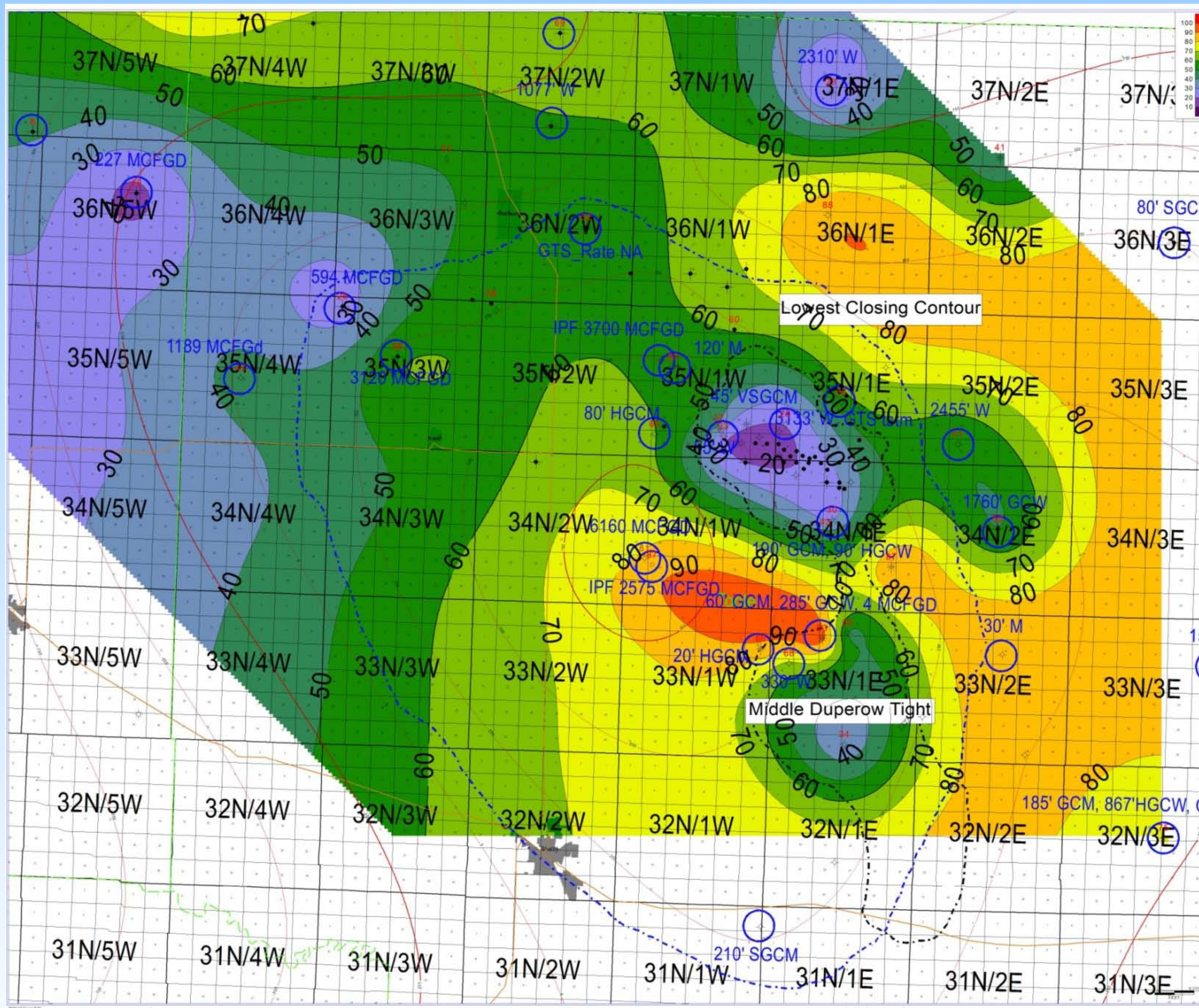
# Middle Duperow Reservoir and Trap, Kevin Dome

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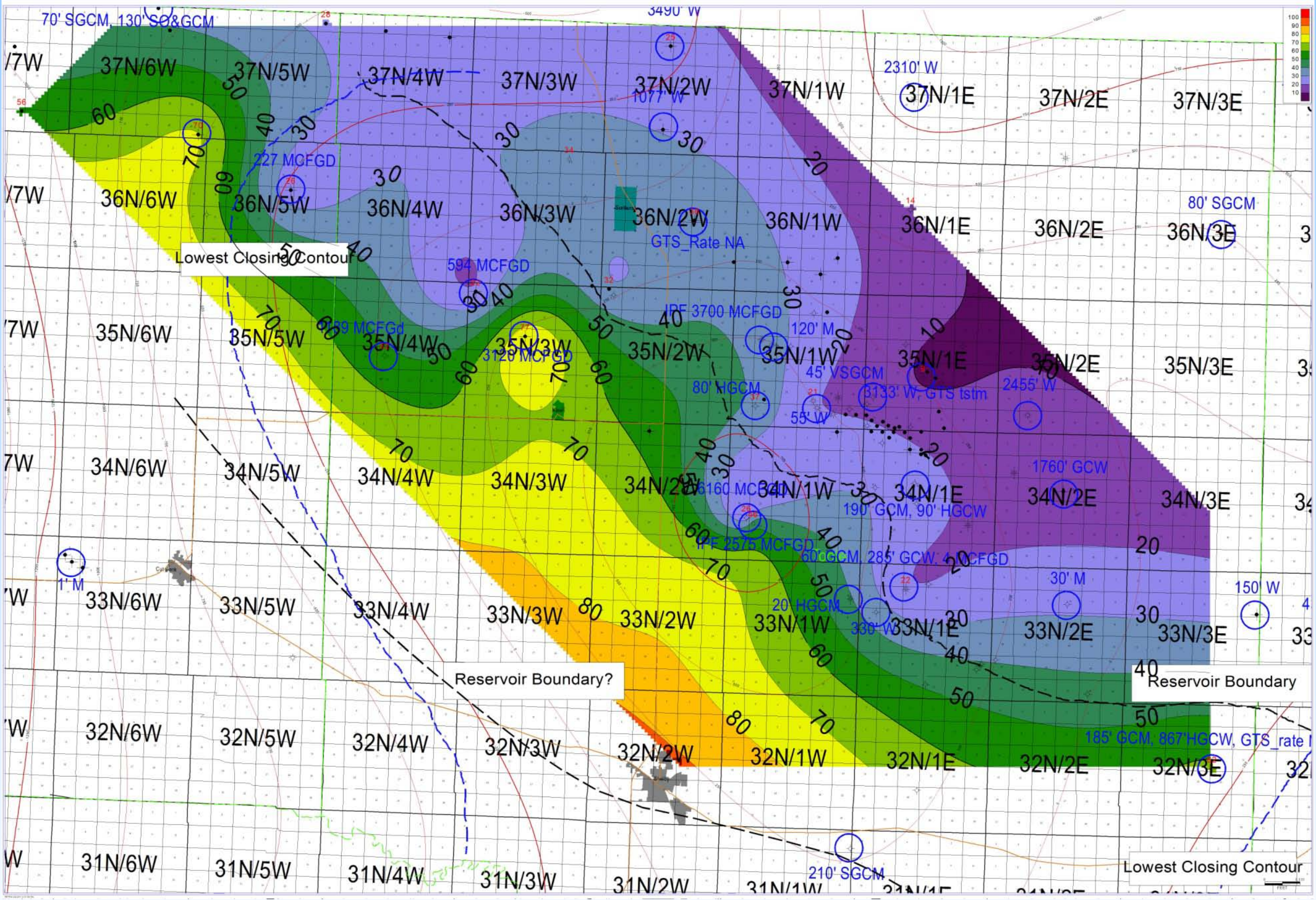
# Lower Duperow Reservoir and Trap, Kevin Dome



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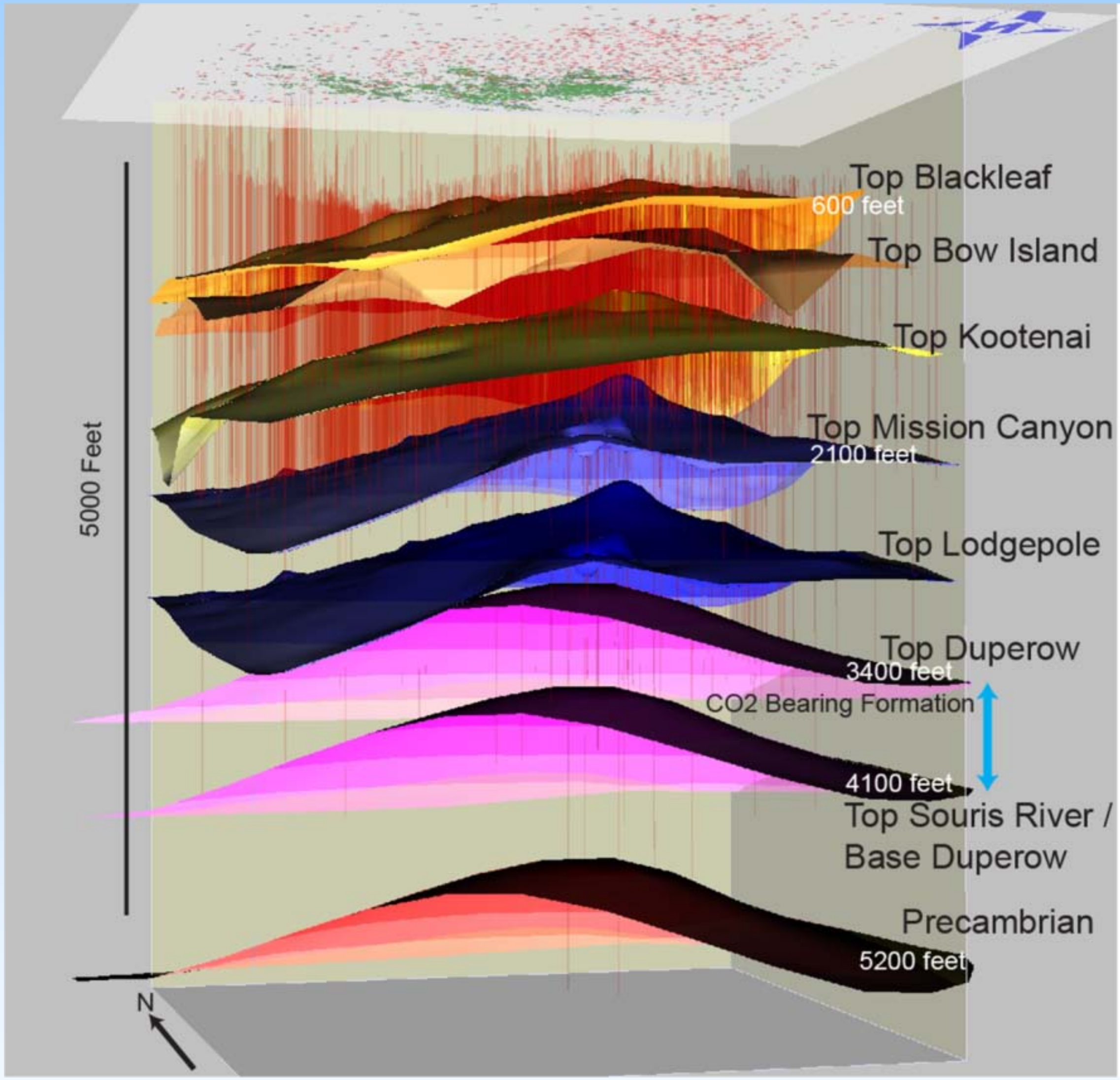
# 3d Reservoir Model

Kevin Dome

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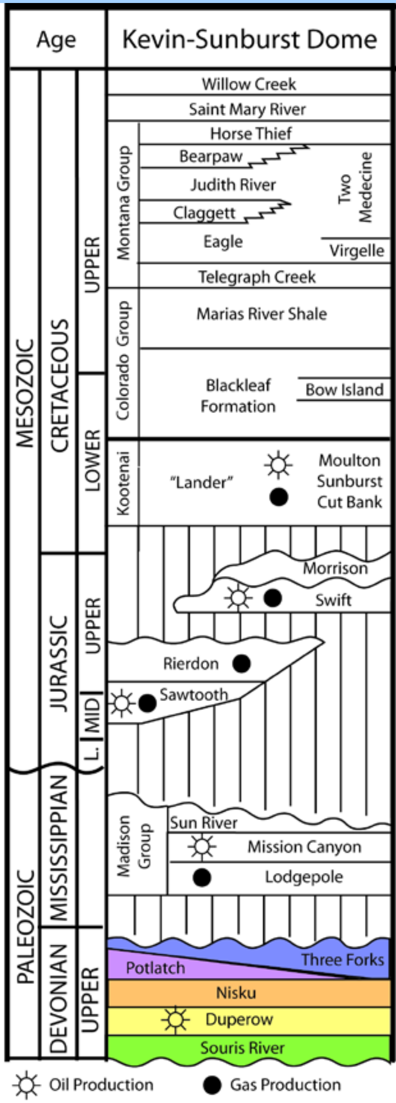
# Geology of Kevin Dome

- Structure of dome is very large: over 750 square miles of closure
- $CO_2$ is naturally trapped in the Devonian Duperow (dolomite) Formation proving *seal integrity*, *compatibility* of formation with $CO_2$, and *trap integrity* over geologic time
- Potentially 10+ TCF $CO_2$ in place (~600MM tons) in two porosity zones
- Structure is not full to the spill-point with $CO_2$ at the Duperow level
- A brine aquifer extends beyond the limits of the dome →greater potential for sequestration
- The Nisku (predominantly limestone) contains some small zones of porosity and permeability
- The Souris River formation may have sequestration potential, but there is very little well control to confirm
- The Potlach Anhydrite caps the Nisku, tight carbonates with interbedded evaporites cap the Duperow and separate the upper and lower Duperow

# Stratigraphy

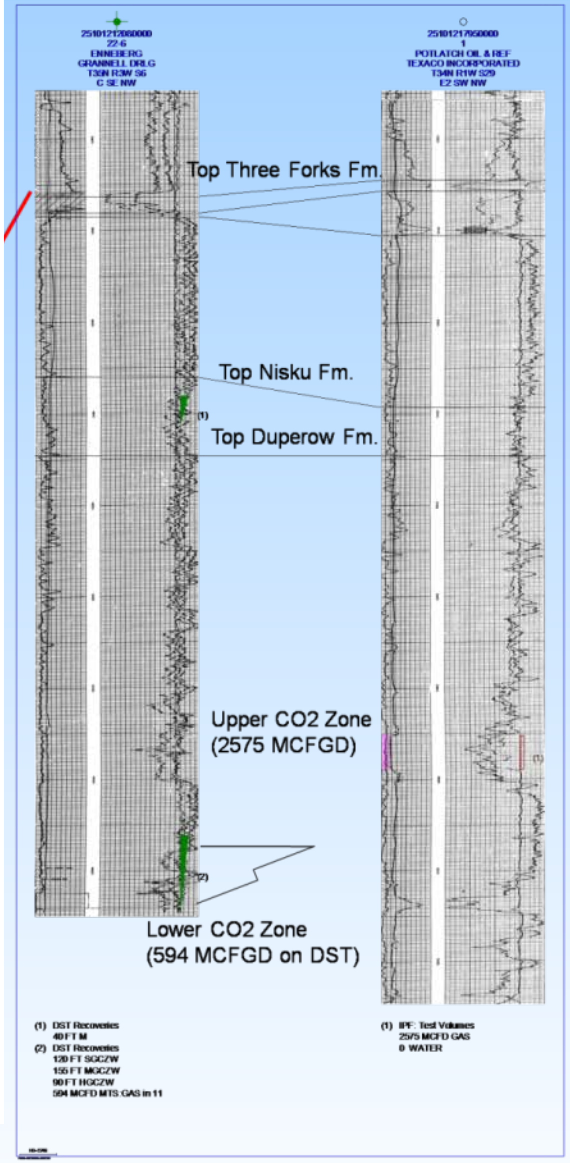



**Potlach Formation**
**Lithology:** anhydrites
**Thickness:** ~ 175 ft
**Importance:** impermeable seal/caprock, natural trap

**Nisku Formation**
**Lithology:** limestone
**Thickness:** ~ 50-75 ft
**Porosity:** 10-25 ft thick porosity zone
**Importance:** potential storage resource

**Duperow Formation**
**Lithology:** dolostone
**Thickness:** ~700 ft total
**Total Dissolved Solids:** >100,000
**Porosity:** 10-15% with interbedded anhydrites
**Importance:** the formation is a naturally occuring, static bouyancy $CO_2$ trap with the potential to store >1GT of additional $CO_2$.

**Souris River Formation**
**Lithology:** carbonates
**Importance:** potential $CO_2$ storage resource

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Caprock Upper Duperow Anhydrites

100 feet

**Nisku Limestone ~ 50 – 75 ft total thickness with a 10 – 25 ft thick porosity zone**

**Potlach Top**

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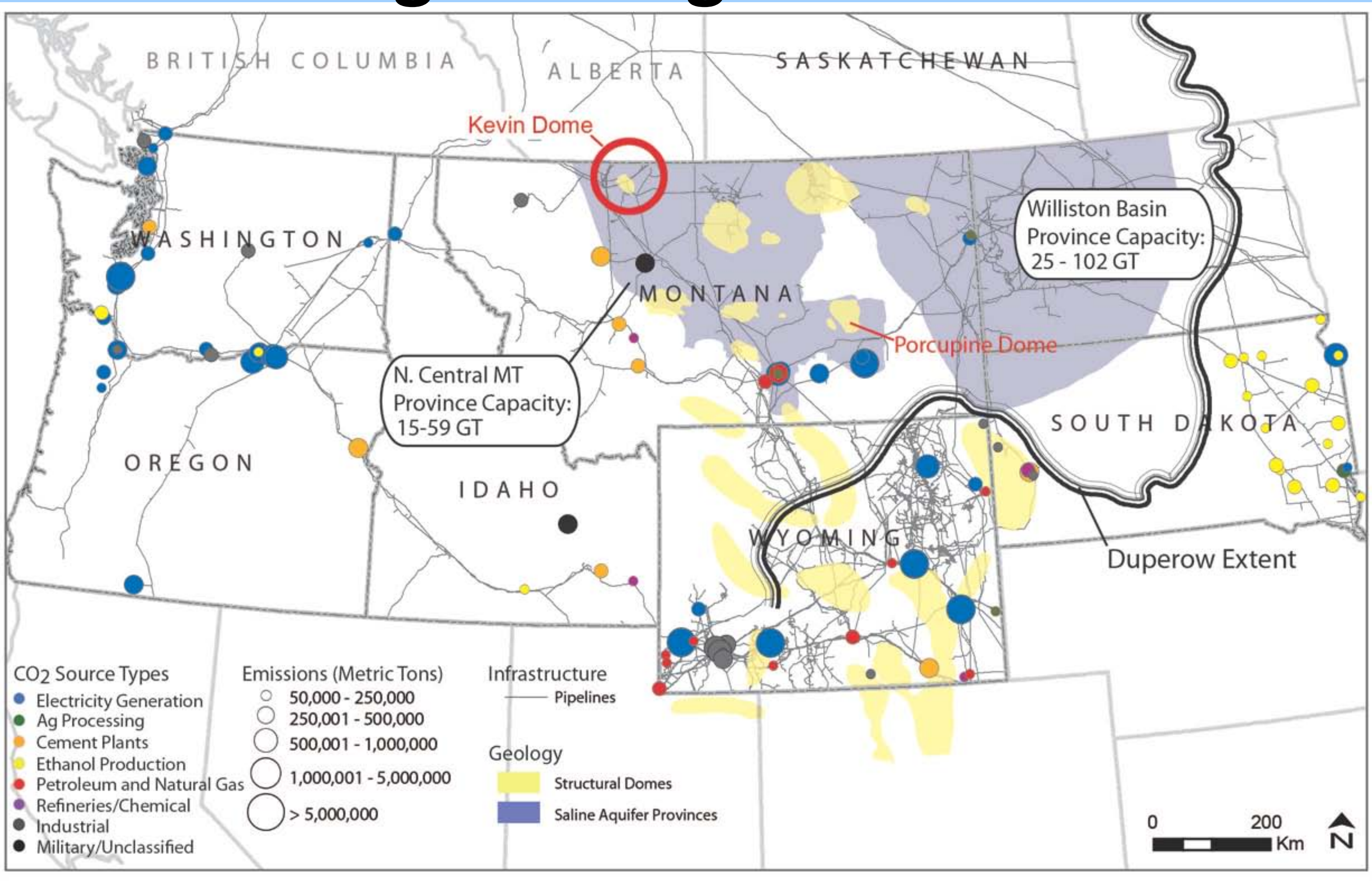
# Regional Significance




- **The Duperow has large potential capacity in central Montana and the Williston Basin**
- **Large structural closures, and in particular, domes, represent an attractive early sequestration target in the Big Sky region.**

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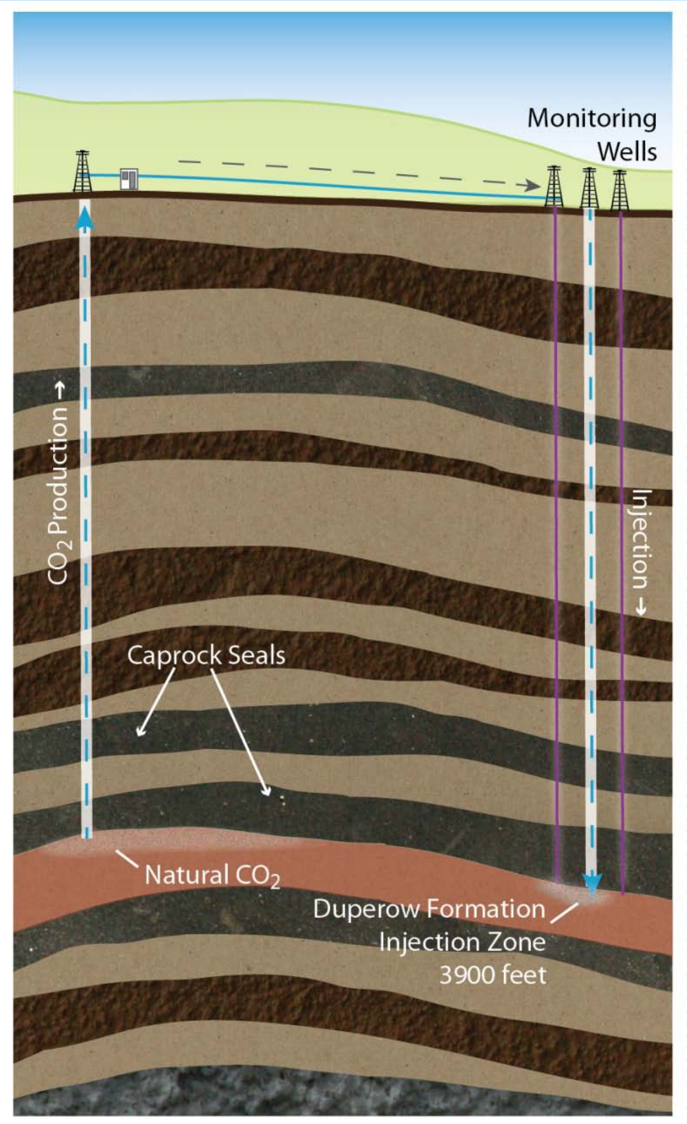
# Project Design Philosophy




- Drill into natural accumulation, Product it, Pipe CO2 laterally, re-inject it
- Decisions on how to do this affects the amount of science that results from the project
- We can leverage
  - Site Properties and Characteristics,
  - Team Capabilities and Expertise,
  - Existing Collaborations
- We should consider what research issues can be addressed by this project while still meeting DOE program requirements (these are well aligned anyway)
- Not many large scale demonstration projects are pursued world wide – we should do what we can to maximize what we learn from them and share knowledge and opportunities

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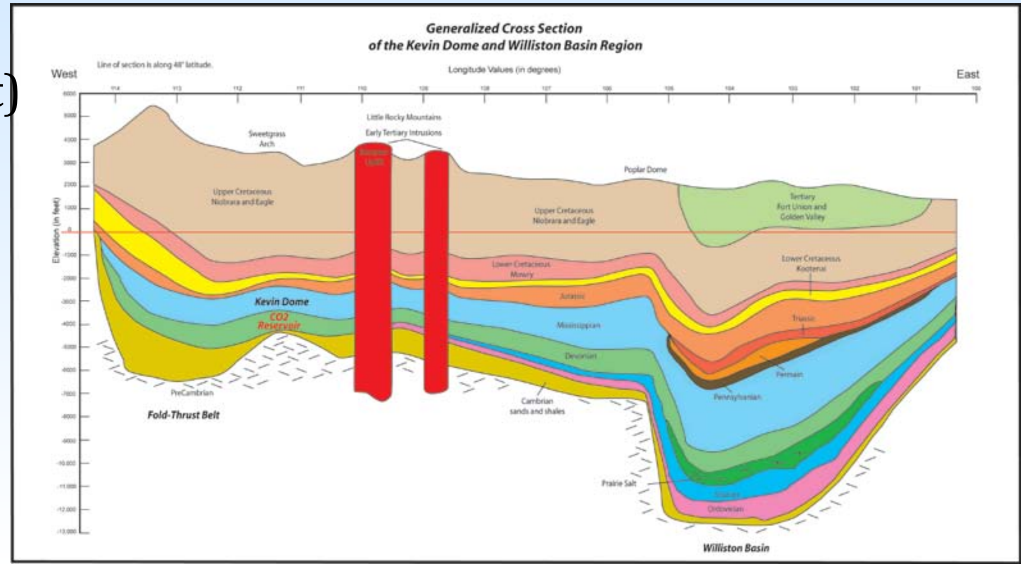
# Site Properties and Characteristics

- We must drill our own producing wells
  - Opportunity to study the natural accumulation
  - Opportunity to study long term effects
  - Turns $CO_2$ procurement cost into research opportunity
- $CO_2$ is in a reactive rock
  - Opportunity to study geochemical effects on both reservoir rock (long term fate of $CO_2$) and caprock (storage security)
  - To accomplish this, injection should be in water leg of the same formation
  - Still retain engineered system learnings on injection, transport, capacity, etc.
- Wells are shallow and relatively inexpensive
  - Potential to have more monitoring wells
  - Can afford cores, logs (lower rig cost)
- Duperow has two porosity zones
  - Opportunity to perform stacked storage or detection limit test depending on the fluid fill in second porosity zone

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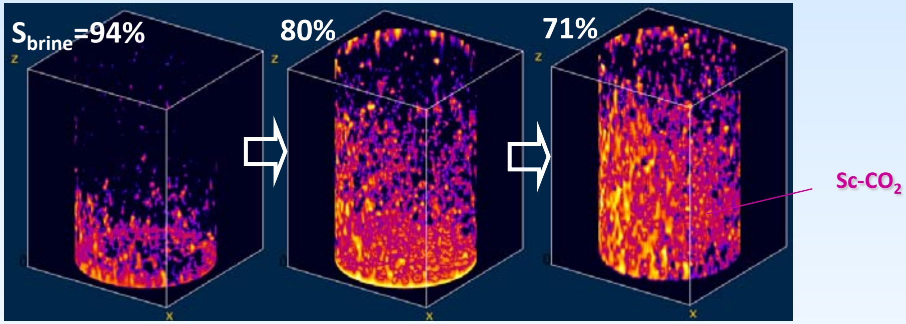
# Project Team Members

| Universities | Private Companies | National Laboratories |
| --- | --- | --- |
| Montana State University | Bison Engineering Inc. | Los Alamos National Laboratory |
| Oregon State University | Vecta Oil and Gas | Lawrence Berkeley National Laboratory |
| Washington State University | Altamont | Idaho National Laboratory |
| Columbia University | Schlumberger Carbon Services | |
| Barnard College | Seismic Reservoir 2020 | |

# Team Capabilities and Expertise

- Strong Geophysical Partners (Vecta, SR2020, Schlumberger
  - Sophisticated logging, downhole measurements
  - Multi-component seismic
  - Main cost share partners so every DOE dollar spent on geophysics returns $1.25 - $2.00
  - Coupled with cheaper monitoring wells
- Excellent core flood & flow facilities
  - Parallel studies for geochemical rates, induced permeability changes, etc.
  - Data to inform coupled model efforts
- Strong Geochemical partners
  - Natural and introduced tracers
  - U-tube technology, monitoring wells
- Strong Modeling team
  - Comprehensive suite of codes
- Development of near surface monitoring
  - Opportunity to learn about deployment

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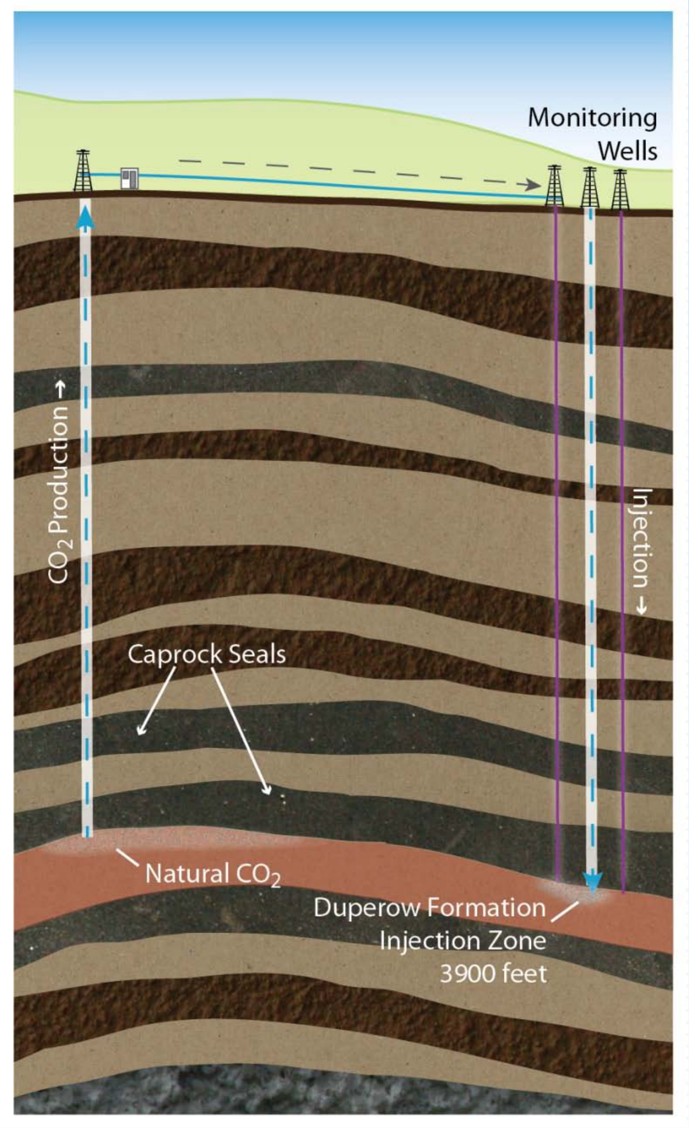
# Leveraging Partnerships and Programs

- Kevin Dome geologic study under Phase II
- $CO_2$ specific modifications to Tough codes accomplished under ZERT, working relationship with LBNL established
- INL involvement in Phase II, Shell sponsorship of Rare Earth Tracer development
- ZERT contributed to CO2-PENS development, working relationship with LANL established
- Working with Schlumberger on other projects
- Vecta relationship with MSU already established
- Assurance monitoring techniques developed under ZERT
- Most other team partners involved in Phase II
- International interest in collaboration, data, sample, knowledge sharing through interactions developed under CSLF, ZERT, NSF Global Scientists, existing collaborations

**The project is an opportunity to test experimental monitoring and modeling technologies developed under other programs**

# Project Overview

- Permitting & Public Outreach
- Site Characterization
- Infrastructure Development
  - 5 Production Wells,
  - 1 Injection Well,
  - 4 Monitoring Wells, Pipelines Compressor
- Injection Operations – 4 years
- Monitoring & Modeling
- Site Closure



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# Scope of Work

**Task 1.0 – Regional Characterization**

Includes regional geologic resource studies, contribution to carbon atlas, terrestrial sequestration, & economic analysis

**Task 2.0 - Outreach and Education**

Project specific community engagement, development of outreach materials, legislative outreach, surveys

**Task 3.0 – Permitting and NEPA Compliance**

Permitting action plan, Permitting for seismic, drilling, pipeline, injection

**Task 4.0 – Site Characterization & Modeling**

Use of existing and acquired cores and cuttings, wireline well logs, petrographic analyses and initial seismic to develop geostatic model, initial mutiphase flow and reactive transport modeling, background assurance monitoring, risk modeling

**Task 5.0 – Well Drilling and Completion**

Well design, drilling of 5 production wells, 1 injection well and 4 monitoring wells, logging and coring

**Task 6.0 – Infrastructure Development**

Well pads, wells, pipeline, compressor, MVA infrastructure

**Task 7.0 – $CO_2$ Procurement**

**Task 8.0 – Transportation & Injection Operations**

Site operations & Injection will occur for 4 years, Closure Plan

**Task 9.0 – Operational Monitoring & Modeling**

Crosswell seismic , 3D-9C VSP, tracers, fluid sampling,

**Task 10.0 – Site Closure**

Well reclassification and transfer of responsibility to Vecta

**Task 11.0 – Post Injection Monitoring & Modeling**

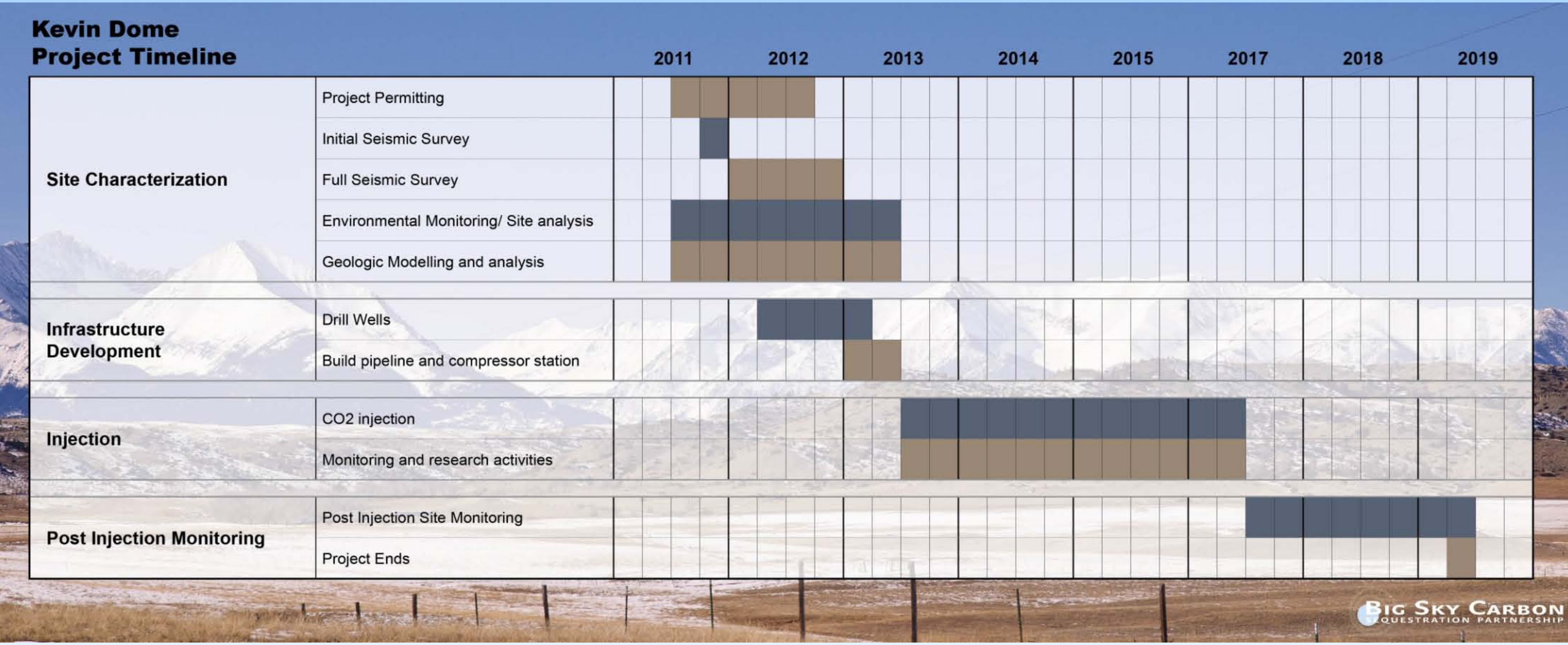
3D-9C surface seismic to create a 4D model, tracers, fluid sampling

**Task 12.0 – Project Assessment**

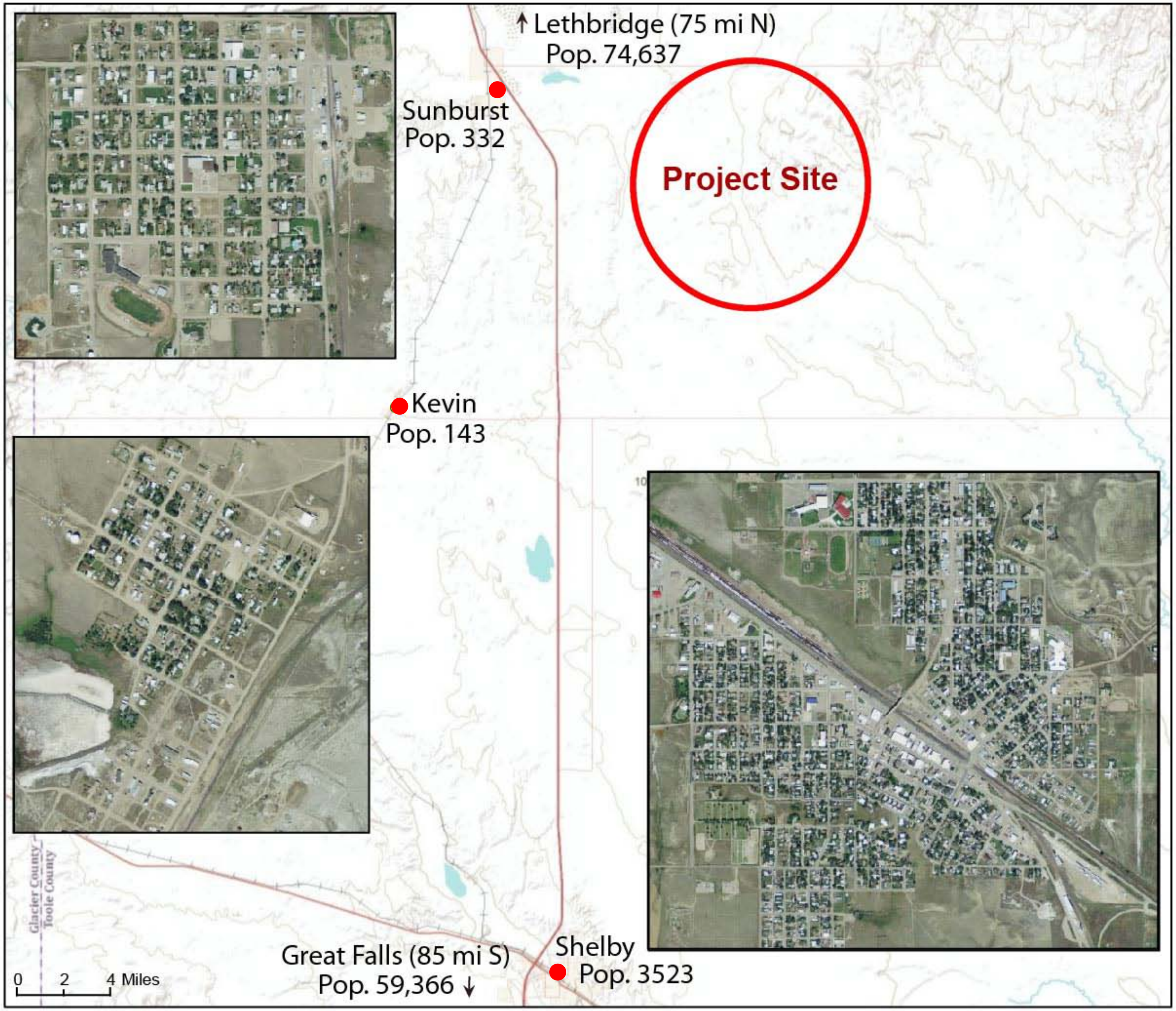
Annual assessment of all project components

**Task 13.0 – Project Management**

# Project Timeline



# Population Centers



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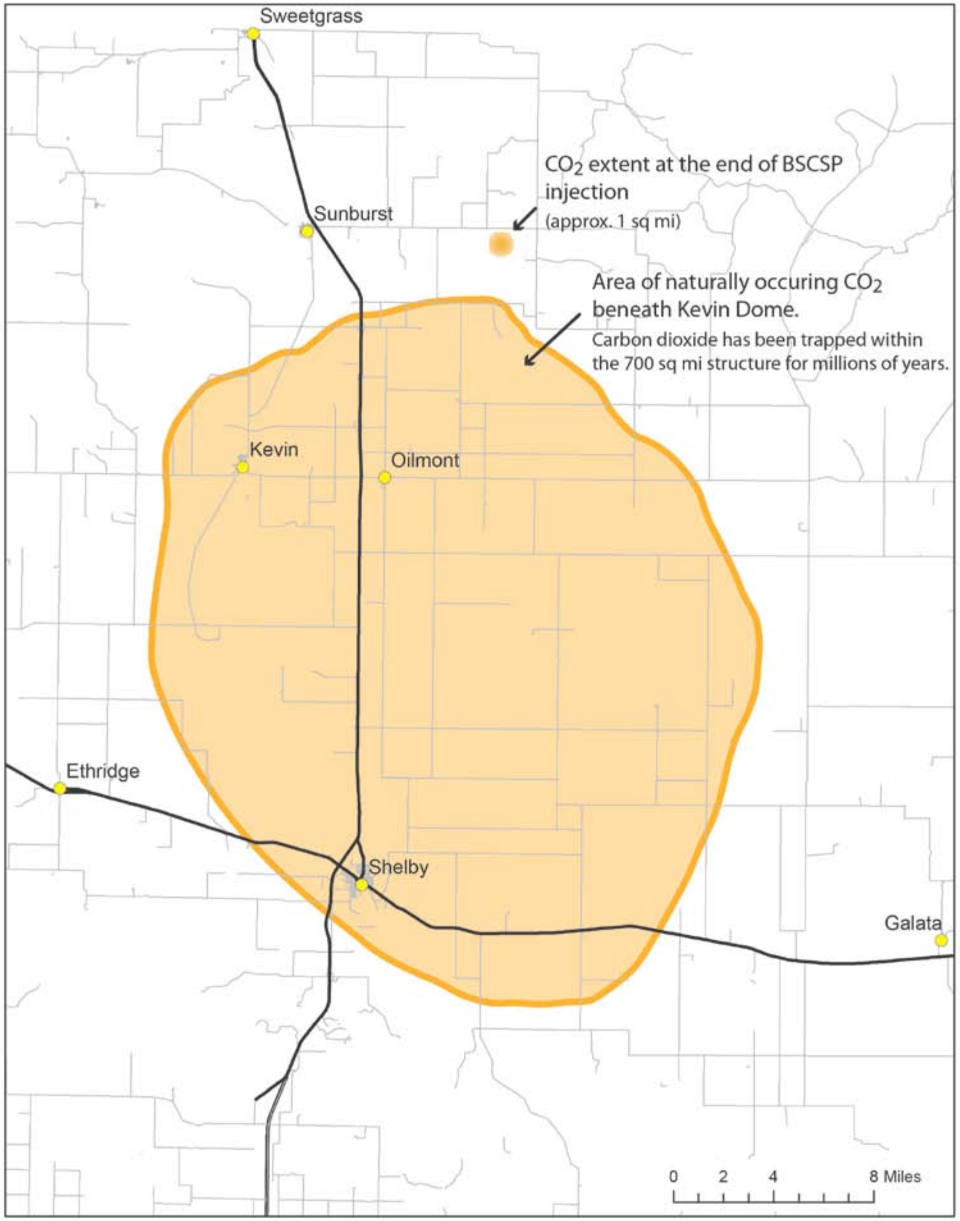
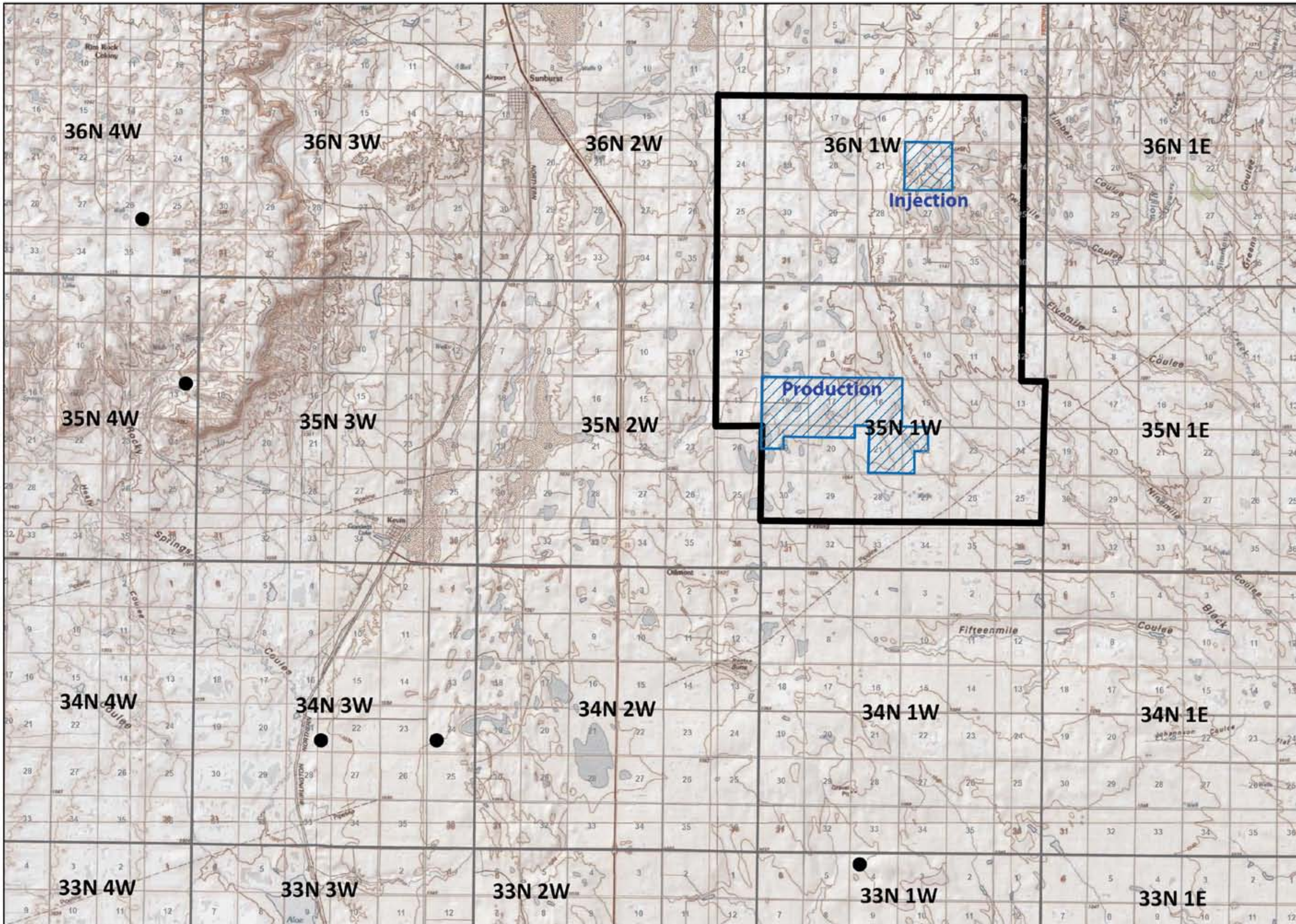
Natural $CO_2$ Accumulation beneath Kevin Dome and the BSCSP Phase III Injection $CO_2$ Extent



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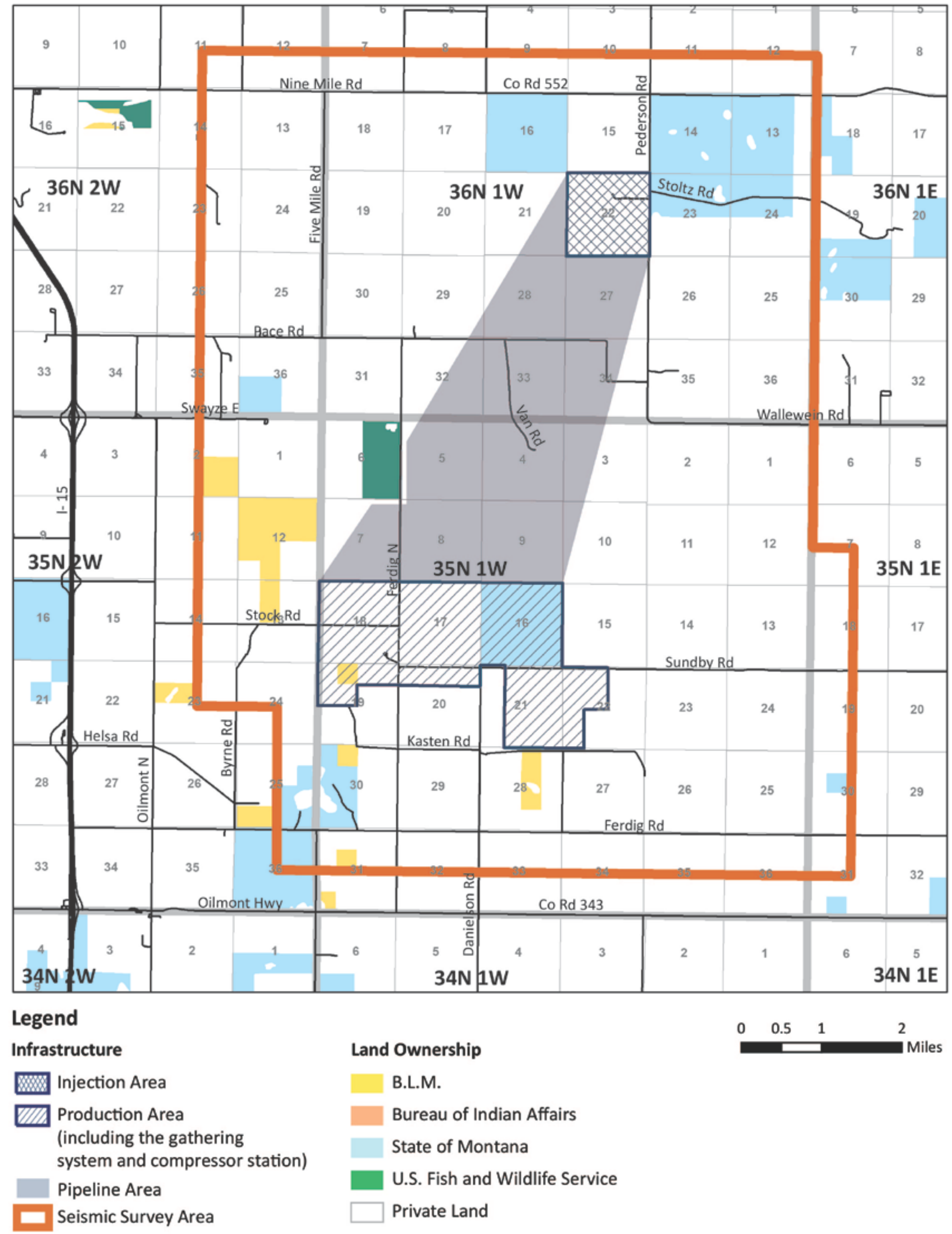
Sept. 28, 2011

# Seismic Area, Production and Injection Zones




**Big Sky Carbon**
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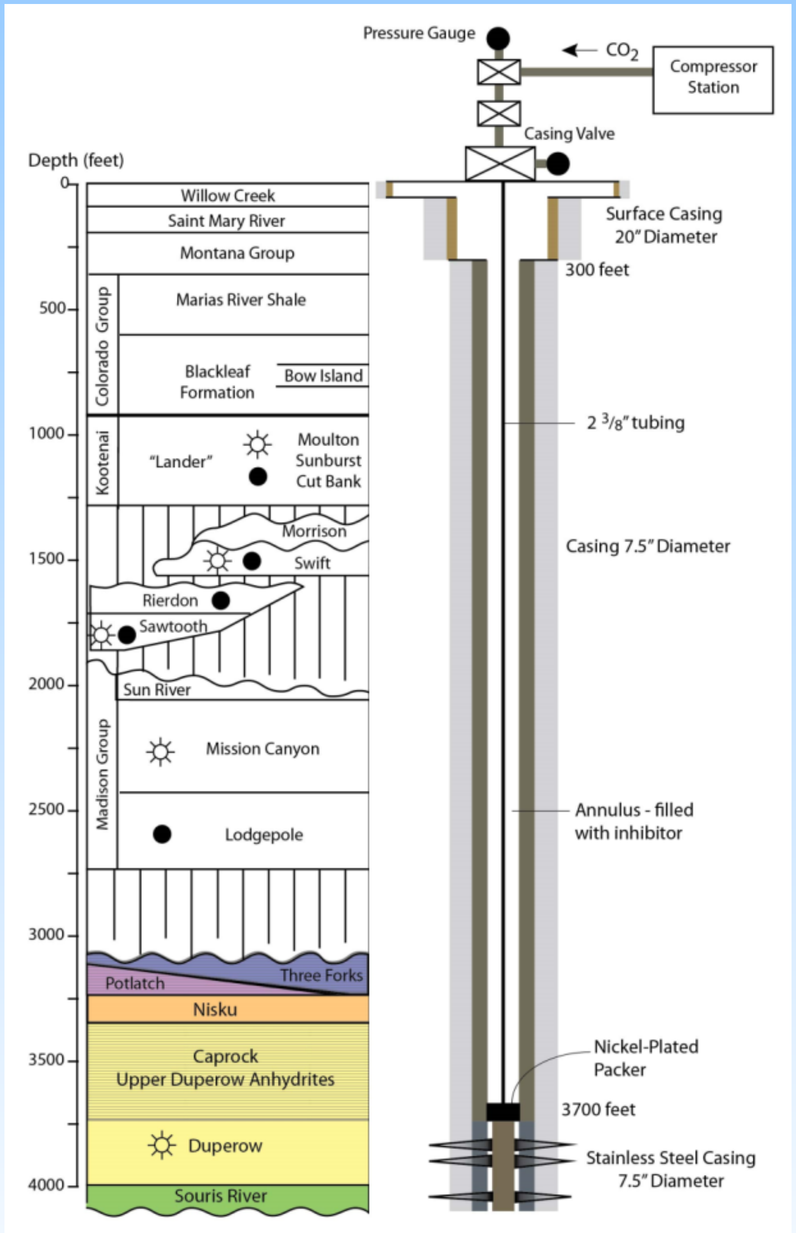
# Task 5 – Well Drilling Injection Well

- Injection Well will be cemented to surface
- 5 in casing will be run to the top of the lower Duperow w/ 5 in stainless steel casing through the Duperow and Souris River Formations
- Nickel plated packer will be set above the perforations of the lower Duperow and Souris River
- To meet Class V well requirements, the annulus will be filled with a water and corrosion inhibitor.
- The use of a dehydrator pre-compression will allow the use of low carbon tubing without the additional expense of chromed or glass lined tubing.
- Well will be instrumented for pressure shut off of the compressor



# Task 6 – Infrastructure Development

- 2 Stage 700hp compressor w/ glycol dehydration
  - Injection rates of 12 to 13 MMCF/day
  - Injection pressure ~1560psi
  - Inlet pressure estimated to be 550 to 700psi
- Pipelines
  - Gathering system
  - Pipeline to injection well
- Data Management System
- Assurance monitoring instruments

# Modeling

## The LBNL TOUGH Codes

### Karsten Pruess et al.

- TOUGH: Transport Of Unsaturated Groundwater and Heat

| | |
|---|---|
| multidimensional | 1D, 2D, 3D |
| multiphase | liquid, gas, NAPL, solid ppt |
| multicomponent | water, air, $CO_2$, tracers, etc. |
| nonisothermal | heat |
| flow and transport | multiphase Darcy law |
| fractured-porous media | dual-$\phi$, dual-k, MINC, ECM |

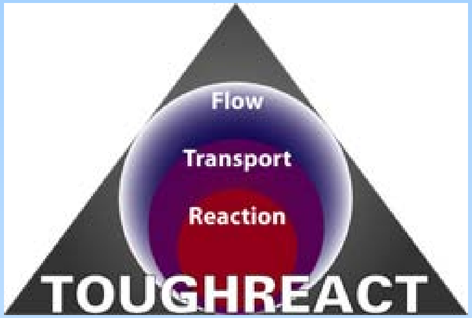
- **Includes a diverse set of Equation of State (EOS) modules**
- **Major variants: TOUGHREACT, TOUGH FLAC, iTOUGH2**

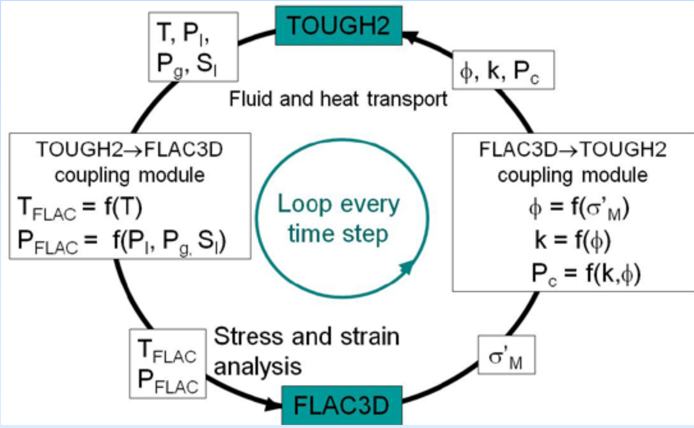


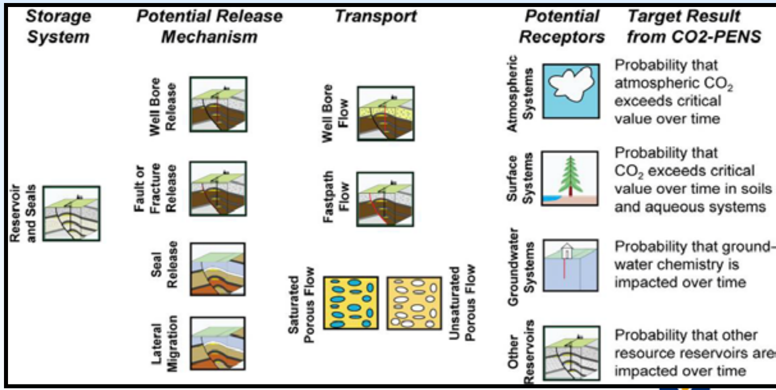
**http://esd.lbl.gov/TOUGH2/**

# Modeling

- Geostatic Model (Petrel)
- Multiphase Flow and Reactive Transport Modeling (Eclipse, TOUGH2 and TOUGHREACT)
- Modeling of Geomechanics and Caprock Sealing Performance (TOUGH-FLAC)
- Coupled Reactive Transport - Geomechanical Modeling (TOUGHREACT-FLAC)
- Geochemical Modeling
- Risk Management and Modeling (CO2-PENS)

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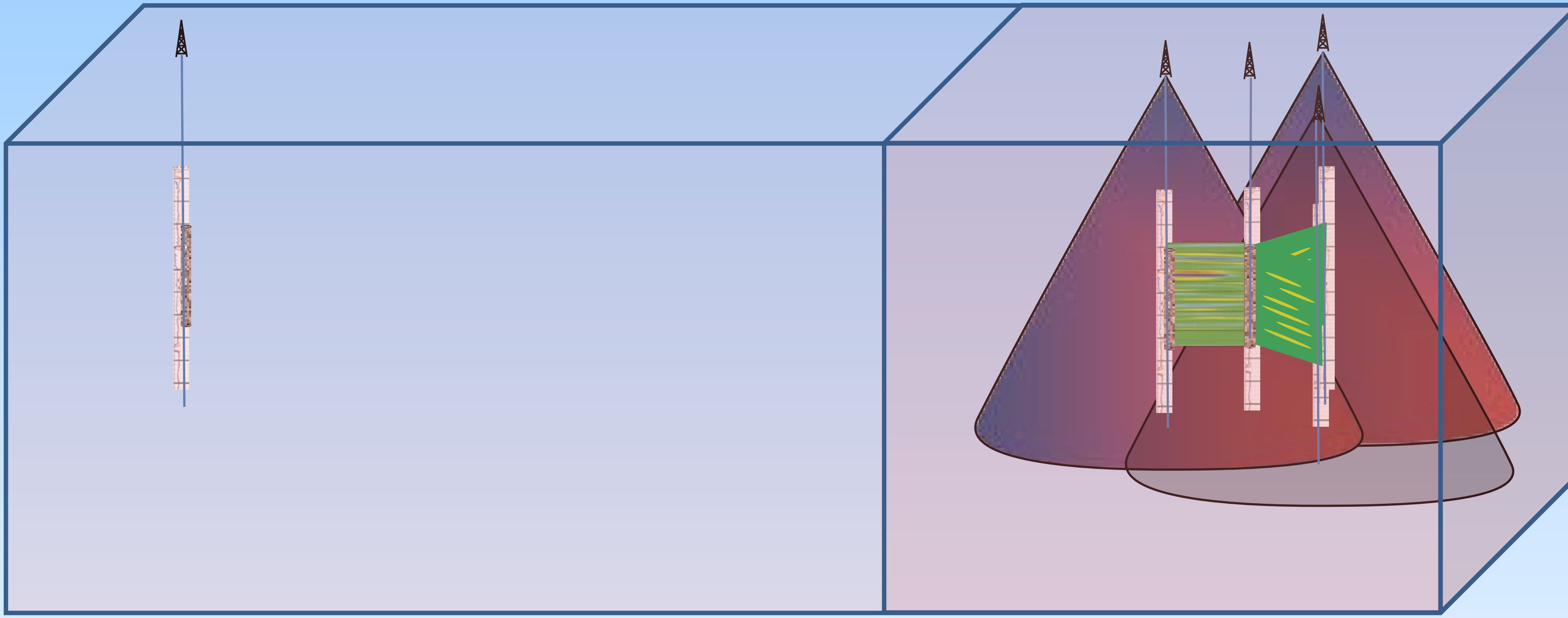
# Geophysical Program



- 58 sq mi 3D, 9C surface seismic covers CO2 saturated and Brine Saturated zones
- Core CO2 saturated and Brine Saturated zones reservoir & cap for geochem studies
- Log all wells. Correlate logs and cores in multiple wells and as function of saturation
- Cross well seismic shot between wells with logs (and some cores) follows early plume
- 9C VSP used to follow most of injection and plume development
- Final 3D 9C surface seismic. Geophysical dataset contains multi-scale data

# Geophysical Characterization & Monitoring Well Logging

- All wells
  - Cement bond, Gamma / Density-Neutron, Resistivity, Sonic
- 1 Producer, Injector 4 Monitoring Wells
  - FMI, RST, MDT
- Annual Logging
  - Injector - MIT
  - Mon. Well – RST

| Logs | Wells | | | |
|---|---|---|---|---|
| | All | 1st Prod | Inj | Mon |
| Cement Bond | Init | | | |
| Gamma / Neutron | Init | | | |
| Resistivity | Init | | | |
| Sonic | Init | | | |
| FMI | | Init | Init | Init |
| MDT | | Init | Init | Init |
| RST | | Init | Init | Annual |
| MIT | | | Annual | |

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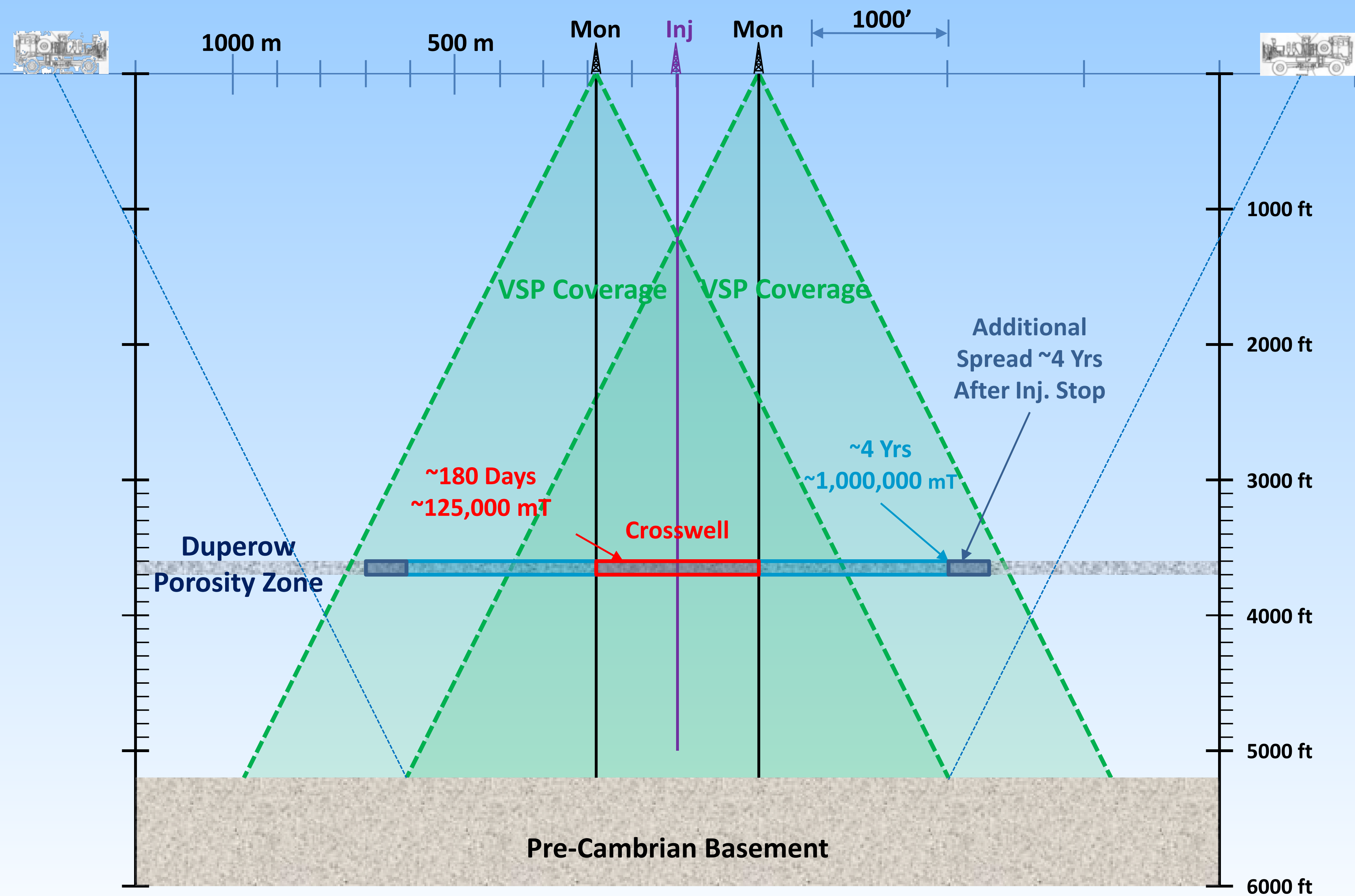
# Vecta has technological skills ideally suited to the Kevin Dome area

- Specialty is multi-component seismic,
  - shear-wave seismic data is a powerful tool for $CO_2$ monitoring and fracture detection in hard rocks
  - Vecta has been successful at imaging stratigraphically complex clastic and carbonate traps in environments similar to Kevin Dome
- Vecta owns its own shear-wave sources and receivers, allowing us to cost-effectively acquire multi-component data


| | Cross Well | VSP (3D, 9C) (Months) | Surface (3D, 9C) (Months) |
|---|---|---|---|
| Seismic Survey Timing (Months) | Initial and 3 repeat surveys in early stages | 0<br>6 | 0 |
| | | 18 | |
| | | 30 | |
| | | 48 | |
| | | | 84 |

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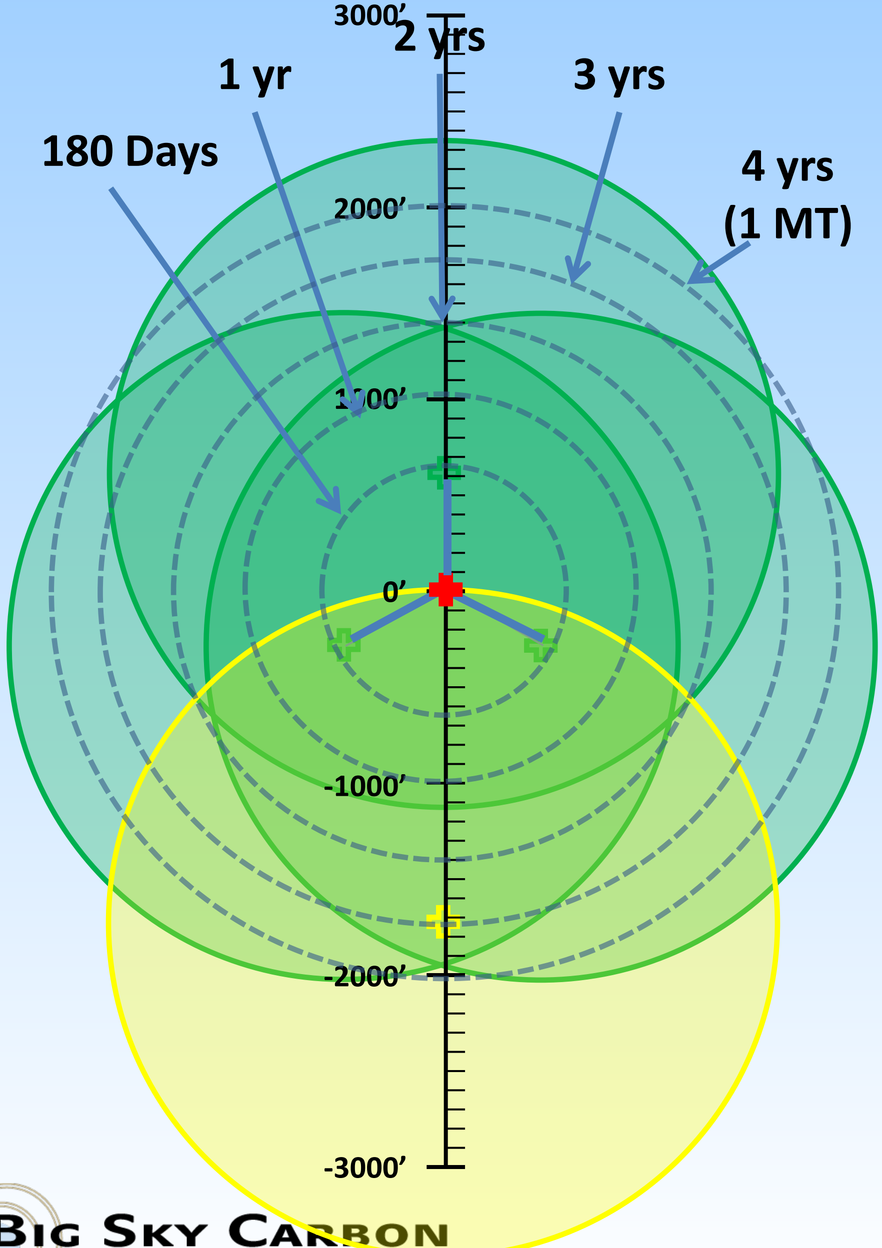
# Monitoring Wells




Preliminary Simulation

Tough2, LBNL

12% porosity

50 mD permeability

700 tonnes / day

Injection Well & X-well Sources

Geophone Wells

Crosswell Lines

VSP Areal Coverage at Duperow

Calculated Plume Boundary

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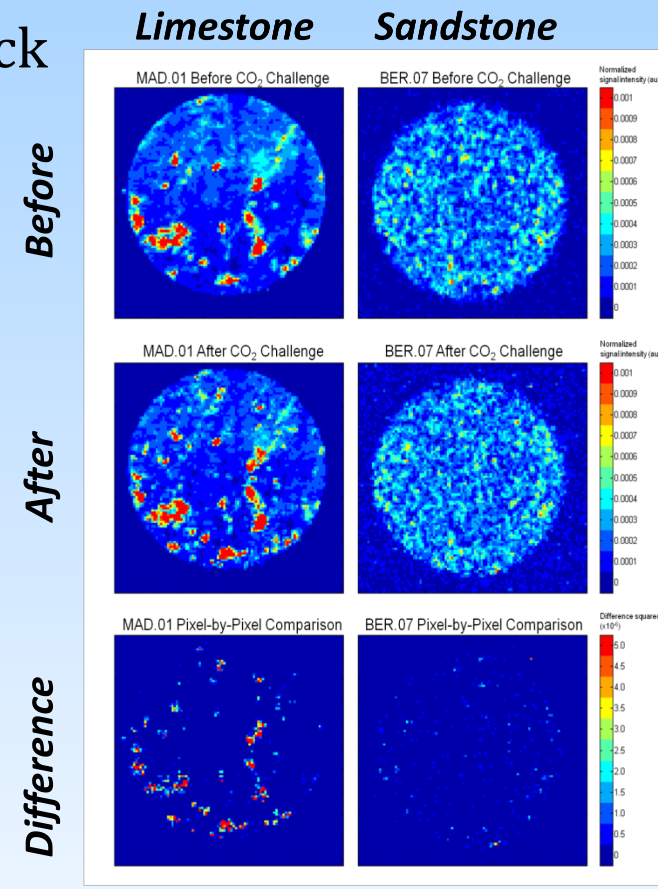
# Cores

- 540 ft of cores to be cut from 1 producing well, the injector and 1 monitoring well
- Coring will include reservoir rock and cap rock
- Side Wall Cores from injector & 1 monitoring well post injection
- Core Testing & Analysis
  - Relative Permeability
  - Rock physics properties
  - Geochemical behavior




**Experimental Design**

- Flow-through Reactor
- Real-time P, T, pH, Cond.
- Sampling of Brine Chemistry

**Physical Changes in Rock Core**

- Microstructure: Optical & SEM
- Porosity: CT & NMR
- Permeability

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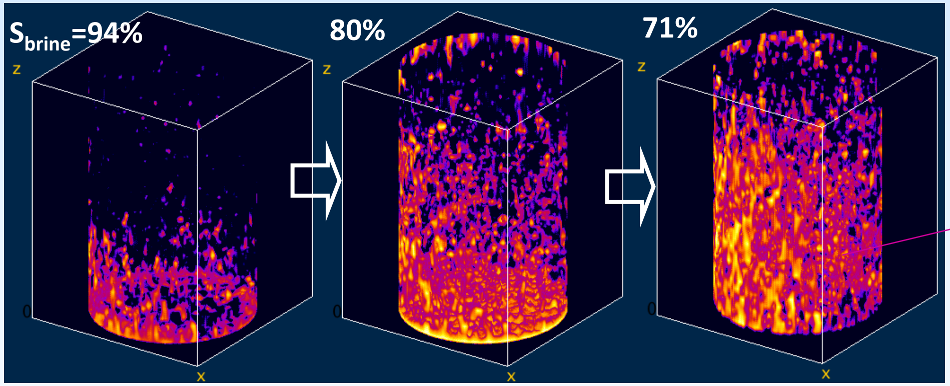
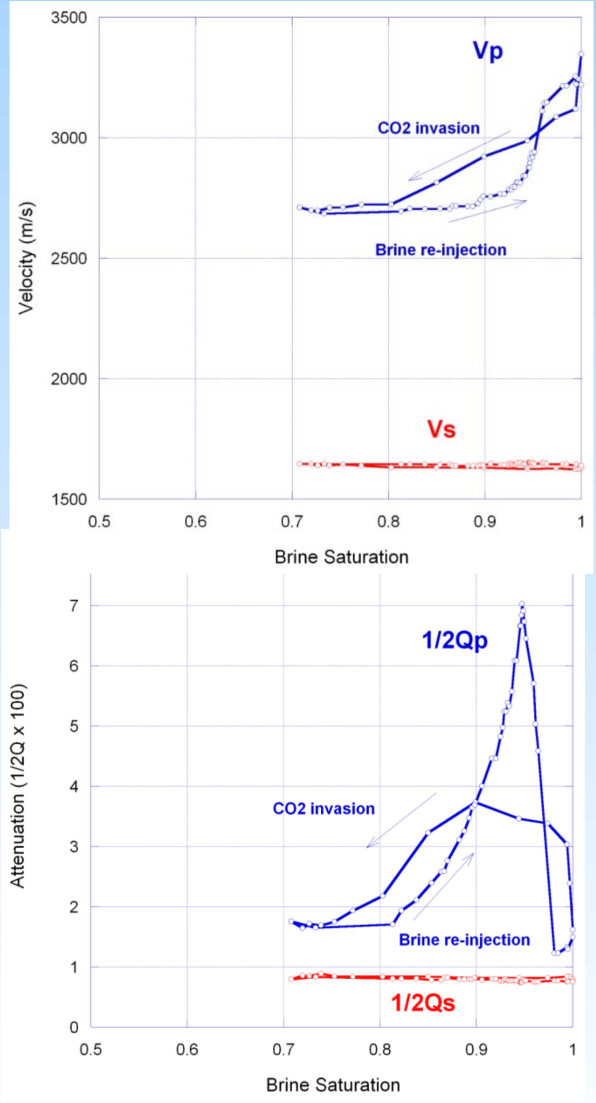
# $CO_2$ Impact on Seismic Properties – LBNL's Split Hopkinson Resonant Bar Apparatus

Resonant Bar Inner Chamber and housing

X-ray CT imaging of resonant bar enclosed in thermal jacket




X-ray images of $CO_2$ core flood




Seismic properties as $f(S_{CO2})$

Courtesy S. Nakagawa and T. Kneafsey, LBNL

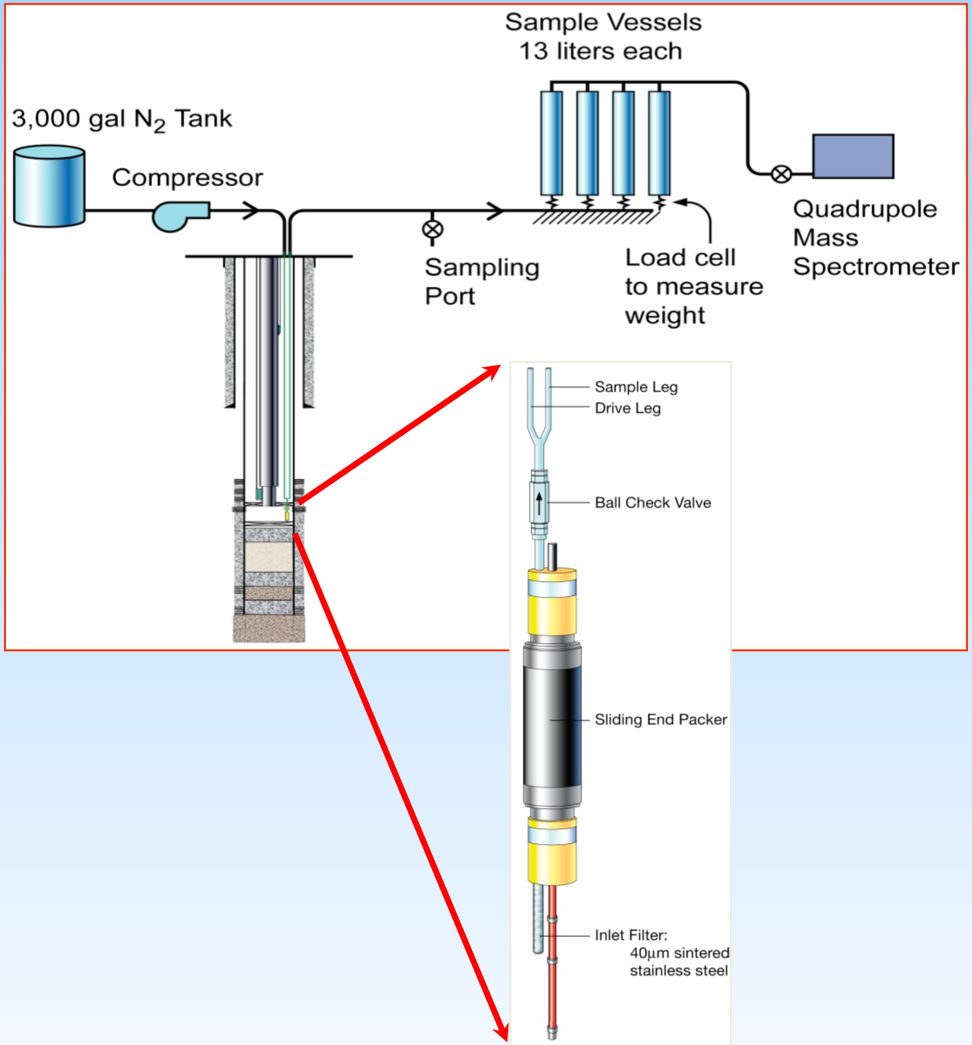
# Geochemical Monitoring

- Fluid Sampling
  - Monthly Via U-tube in all monitoring wells until

| Analyte | Method | Purpose |
|---|---|---|
| Cations (aq) | ICP-MS | Basic water chemistry |
| Cations (s) | Microprobe, ICP-MS (whole rock digestion) | Whole rock chemistry |
| Anions (aq) | Ion Chromatography | Basic water chemistry |
| Anions (s) | Ion Chromatography (whole rock digestion) | Changes in rock chemistry throughout experiments |
| Mineralogy | XrD | Rock phase determination pre and post experiment |
| REE (s) | ICP-MS, XRF | Water chemistry mineral dissolution ppt |
| Trace elements) (aq) | ICP-MS | Water chemistry evolution |
| Trace elements, including REE | ICP-MS LASER ablation, Microprobe, XRF | Evolution of minerals phase during experiment |
| pH, alkalinity, temp | P-T electrode | Water chemistry |

- Tracers
  - Phase partitioning tracers
  - $SF_6$
  - $^{14}CO_2$
  - Rare earth element
- Core Testing & Analysis
  - $CO_2$ flood and flow experiments
  - Comparison of cores from gas cap with cores from injection zone pre- and post- injection

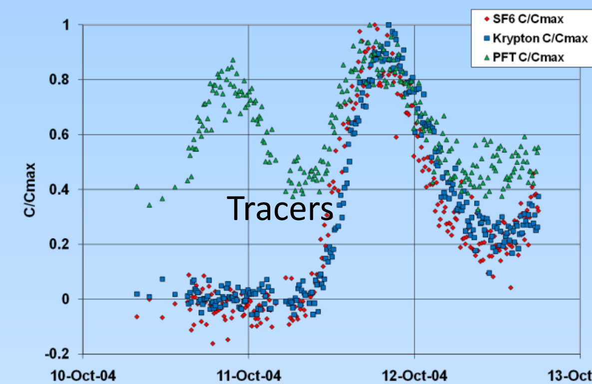
# U-Tube Fluid Sampling – Multiphase samples provide insights into reservoir processes



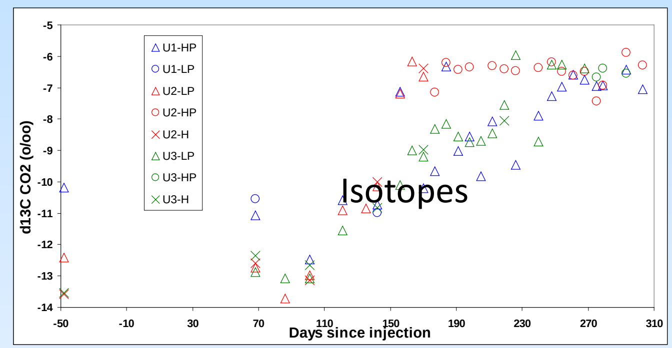

Schematic of initial U-tube System at Frio Brine Pilot

Courtesy B. Freifeld, LBNL

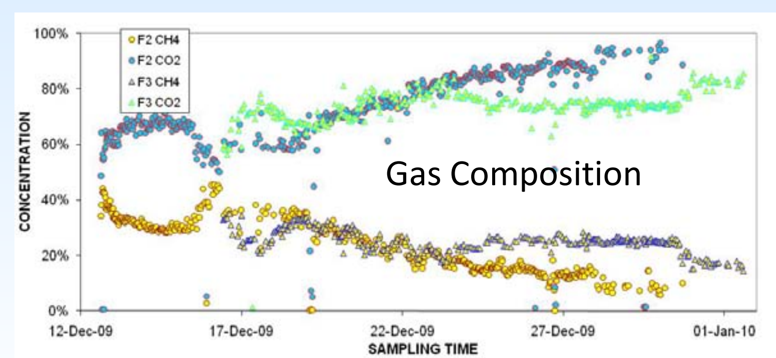
Frio Brine Pilot




Otway Project




SECARB Cranfield

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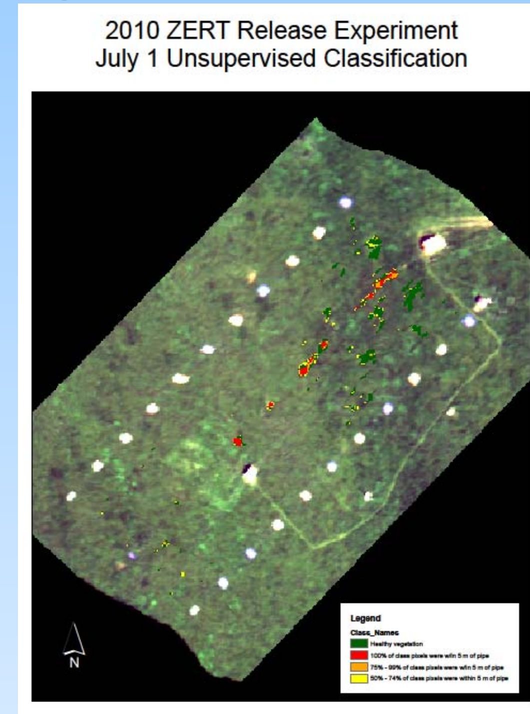
# Assurance Monitoring

- **Eddy covariance**
  - Measure net CO2 flux by calculating turbulent fluxes within the atmospheric boundary layer
  - Spatial scale: $m^2$-$km^2$

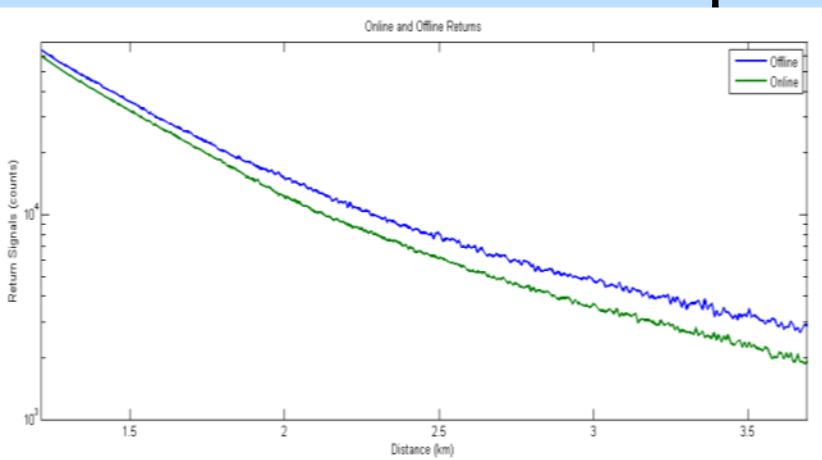
- **Soil flux surveys**
  - Measures soil $CO_2$ flux
  - Spatial scale: point measurements, establish a grid to cover larger areas
- **Drinking water monitoring**
  - pH - temperature
  - Conductivity - alkalinity
  - anions - cations
  - carbonates - nutrients
  - metals - tracers
  - inorganic, organic, and total carbon

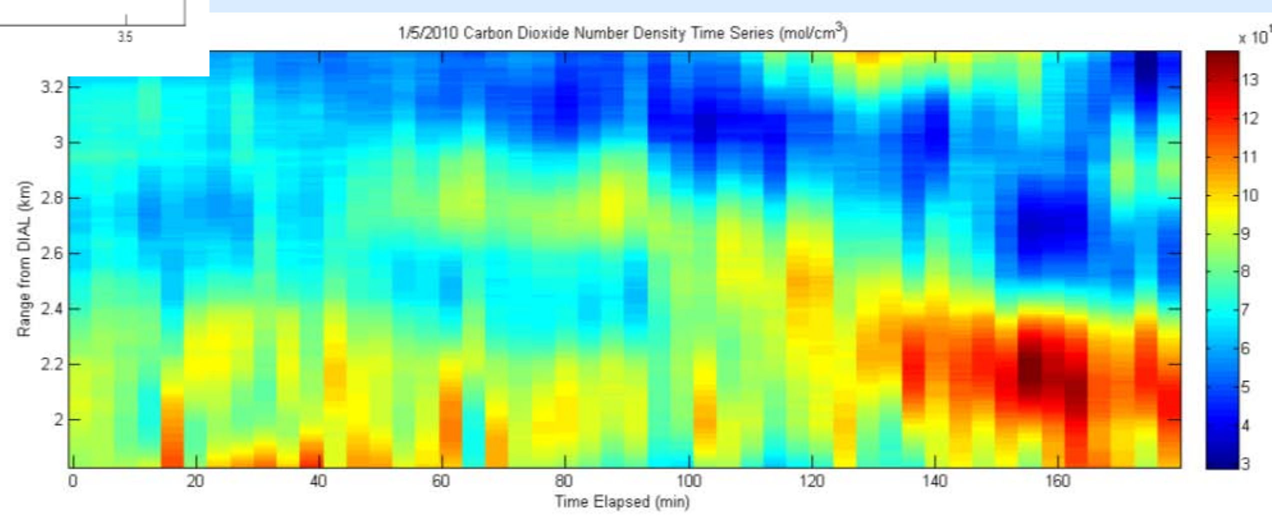
# Assurance Monitoring

- Hyperspectral imaging

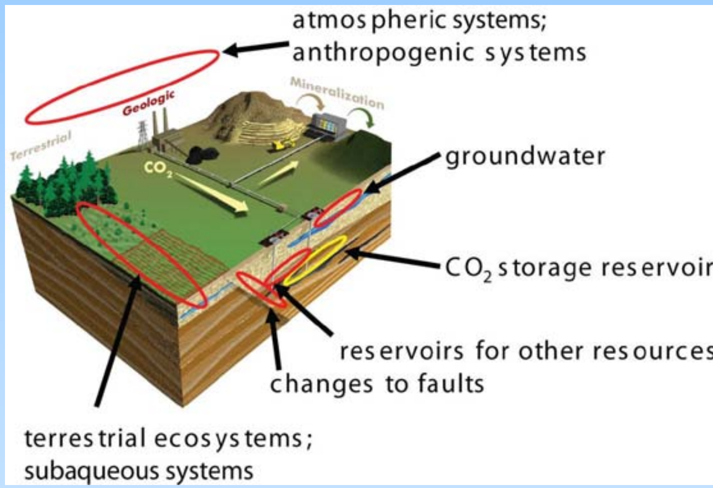




- Differential Absorption Lidar



# Risk Assessment / Management



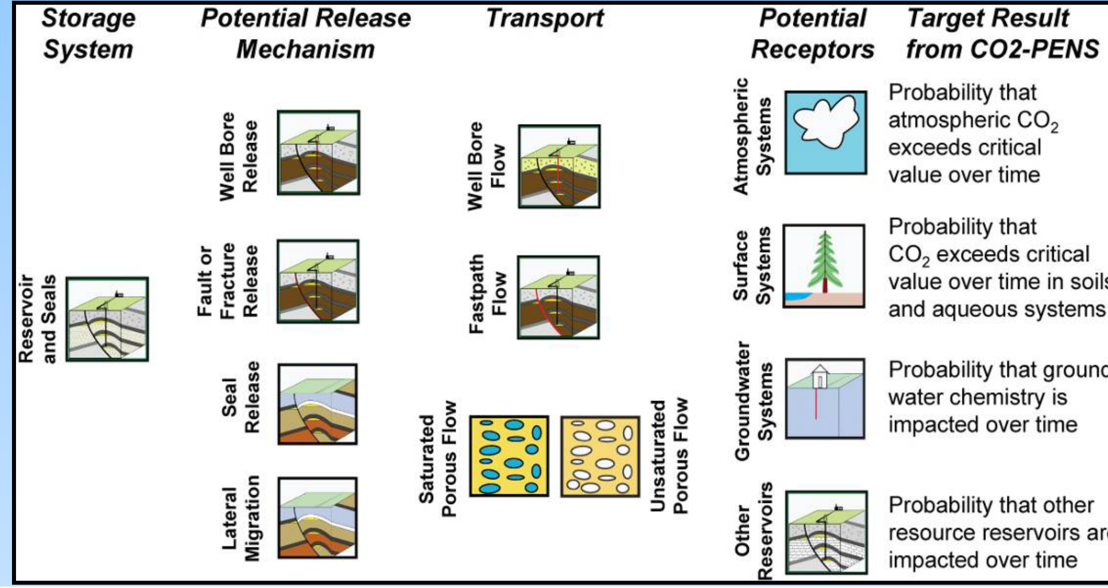




Table 5. Sample risk pathways.

| Risk Pathway | Potential Event | Event Scenarios | Risk Assessment Approach | MVA Approach | Mitigation Strategy |
|---|---|---|---|---|---|
| **Storage Reservoir** | Reservoir has insufficient capacity or injectivity to complete pilot test | $CO_2$ plume reaches maximum extent of reservoir prior to injection completion<br>Pressure increases more rapidly than predicted during injection phase<br>Colloids and other particulates are mobilized and alter permeability field<br>Predicted porosity or permeability field differs from observed. | Uncertainty analysis will provide estimates of variability for key parameters to be fed into $CO_2$-PENS<br>Reservoir model coupled to $CO_2$-PENS simulates capacity/injectivity for various combinations of parameters in Monte Carlo approach. | Preexisting data from site will be used to assess key reservoir parameters<br>Cores will be analyzed as available<br>Plume migration will be monitored with repeat 3D seismic surveys<br>Pressure will be monitored during injection. | $CO_2$ injection will cease if plume exceeds limit of storage reservoir.<br>Additional injection wells could be added if injectivity decreases below desired level. |
| **Groundwater** | $CO_2$ increase in aquifer changes groundwater chemistry | $CO_2$ released from reservoir<br>Water-rock-$CO_2$ interactions change groundwater chemistry | $CO_2$-PENS models the accumulation of $CO_2$ in groundwater due to various release scenarios<br>PHREEQ-C is coupled to $CO_2$-PENS and allows water-rock-$CO_2$ interactions to change groundwater chemistry | Groundwater reservoir characteristics (lithology, porosity, permeability) and background groundwater chemistry will be tabulated from existing sources and used in modeling efforts<br>Groundwater chemistry will be monitored on an annual basis using protocol to be defined. | Groundwater sampling (outlined in MVA) will provide detection of potential releases and potential chemistry change<br>If impact is detected, appropriate water purification technologies can be identified and deployed. |
| **Other Reservoirs** | $CO_2$ (or brine) accumulates in resource reservoir | $CO_2$ (or brine) i from the storage reservoir into other reservoirs | $CO_2$-PENS models the accumulation of $CO_2$ in other reservoirs that are identified in the geologic model. | Fluid samples from other reservoirs will be monitored on a periodic basis as necessary. | If impact is detected, $CO_2$ injection will cease. |

# Risk Assessment / Management

| Risk Pathway | Potential Event | Event Scenarios | Risk Assessment Approach | MVA Approach | Mitigation Strategy |
|---|---|---|---|---|---|
| **Terrestrial Systems** | $CO_2$ increase in soils impacts terrestrial ecosystems and/or surface waters | $CO_2$ released from reservoir<br>$CO_2$ migration to soil zone<br>$CO_2$ accumulation in surface waters. | $CO_2$-PENS models the accumulation of $CO_2$ at surface (e.g., soils and surface waters) due to various release scenarios. | Soil gas surveys will be conducted on a periodic basis as necessary to assess $CO_2$ levels.<br>Surface water chemistry surveys can be conducted on a periodic basis as necessary. | If impact is detected in soils, release site will be identified and mitigation will be used to lower $CO_2$ levels in soil zone.<br>If impact is detected in surface waters, release site will be identified and a mitigation assessment will be developed. |
| **Atmospheric System** | $CO_2$ released to atmosphere making the storage ineffective | $CO_2$ released from reservoir<br>$CO_2$ migration to atmosphere | $CO_2$-PENS models the release of $CO_2$ to the atmosphere and subsequent dispersion assuming boundary layer mixing<br>$CO_2$-PENS results provide estimate of risk due to $CO_2$ levels in excess of critical parameters in various geographic regions as well as estimate of potential to measure release by monitoring atmospheric accumulation | Surface $CO_2$ measurement will provide estimate of variations in concentration relative to predicted scenarios from $CO_2$-PENS | If release is detected, release mechanism will be identified and mitigation of release mechanism will be attempted. |
| **Anthropogenic Systems** | $CO_2$ released to atmosphere making the storage ineffective` | $CO_2$ released from reservoir<br>$CO_2$ migration to surface followed by accumulation in confined space. | $CO_2$-PENS models the release of $CO_2$ to the surface for various release scenarios. | Confined spaces that may be affected based on $CO_2$-PENS assessment will be monitored as necessary. | If release and accumulation is detected, confined spaces will be ventilated. |

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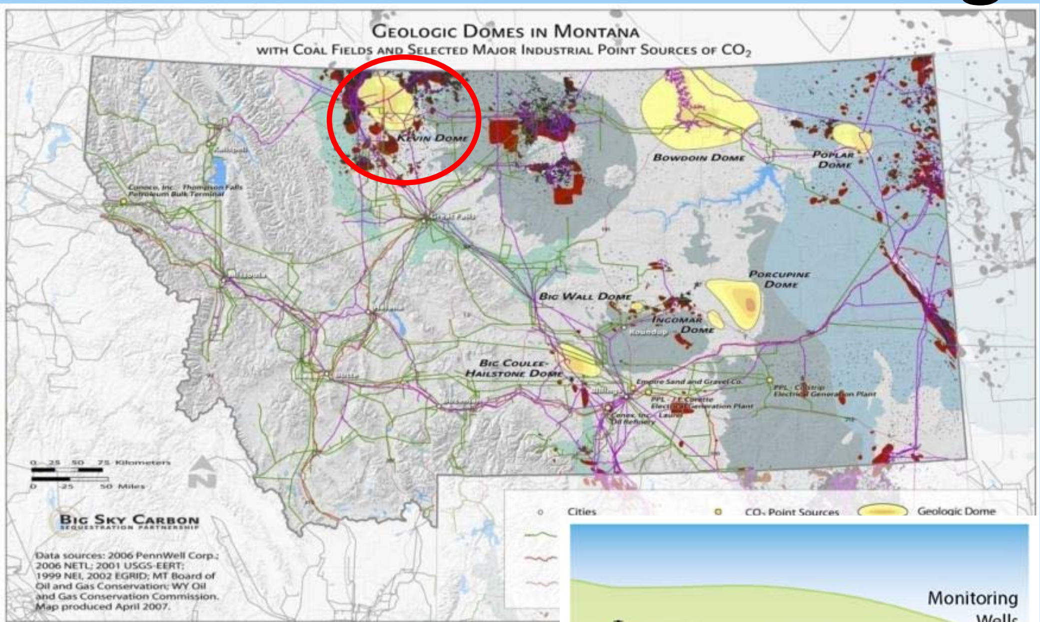
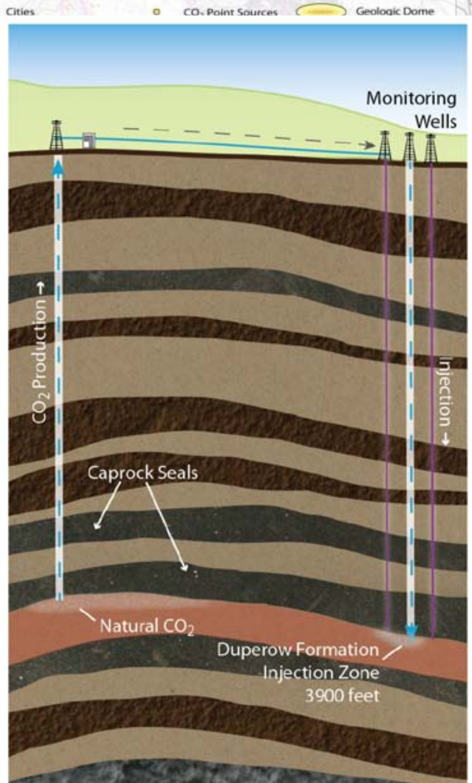
# Project Status

- Negotiations with DOE finalized July 25, 2011
- Kick-off meetings held
  - Project –NETL
  - Project – Internal
  - Permitting
- Outreach activities
  - City Councils, County Commission
  - Two public meetings
  - Landowner meetings
- Permitting & NEPA compliance
  - Interim action near finalization

# Kevin Dome Large Scale Project



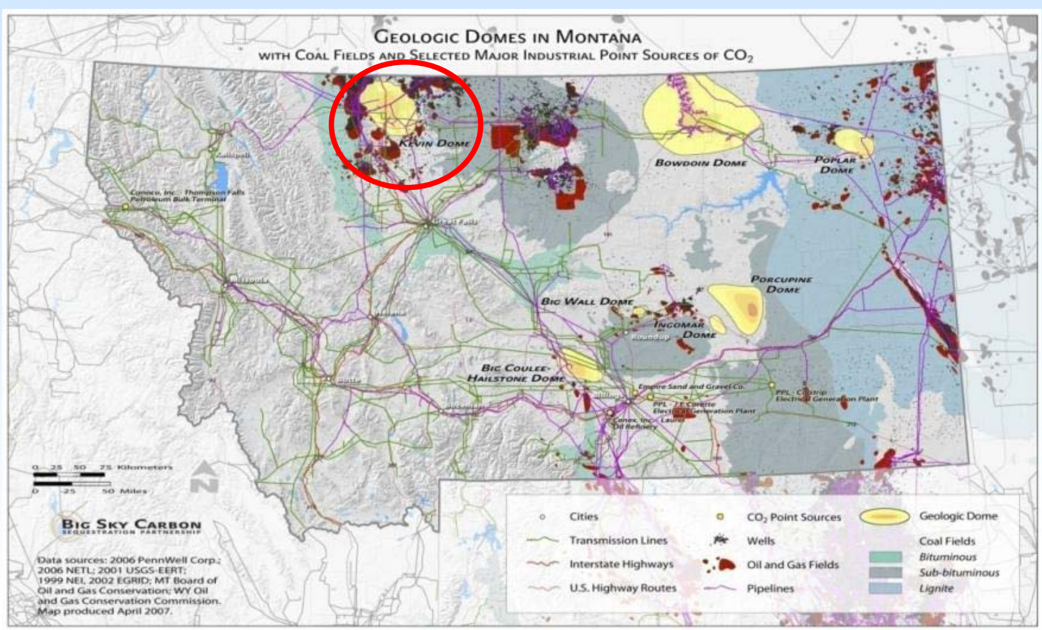




**A Kevin Dome Project Will Allow Study Of:**

- Storage in the regionally significant Duperow.
- Storage in regionally significant domes.
- Comparison of a natural analog to new storage providing long term geochemical data.
- Potential for mitigation method tests (Vecta plans to re-produce $CO_2$ at the end of the project)
- Mutiscale, multicomponent seismic with potential to better understand signals as $f(S_{CO2})$

# Kevin Dome Large Scale Project

- The thin storage reservoir and relatively large number of project wells may allow study of pressure effects in both the storage and production regions
- The natural analog allows us to look at changes in the rock matrix as a function of long exposure and how this might change seismic response
  - This also represents an unusual opportunity for coupled model studies
- The existence of multiple sampling wells, unique rock physics property measurements, and multicomponent seismic combined with plans to reproduce the CO2 represent a unique opportunity to study mitigation methods and understand signals as $f(S_{CO2})$

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# Acknowledgements

DOE & NETL

Team Members

| Universities | Private Companies | National Laboratories |
| --- | --- | --- |
| Montana State University | Bison Engineering Inc. | Los Alamos National Laboratory |
| Oregon State University | Vecta Oil and Gas | Lawrence Berkeley National Laboratory |
| Washington State University | Altamont | Idaho National Laboratory |
| Columbia University | Schlumberger Carbon Services | |
| Barnard College | Seismic Reservoir 2020 | |

# Any questions?

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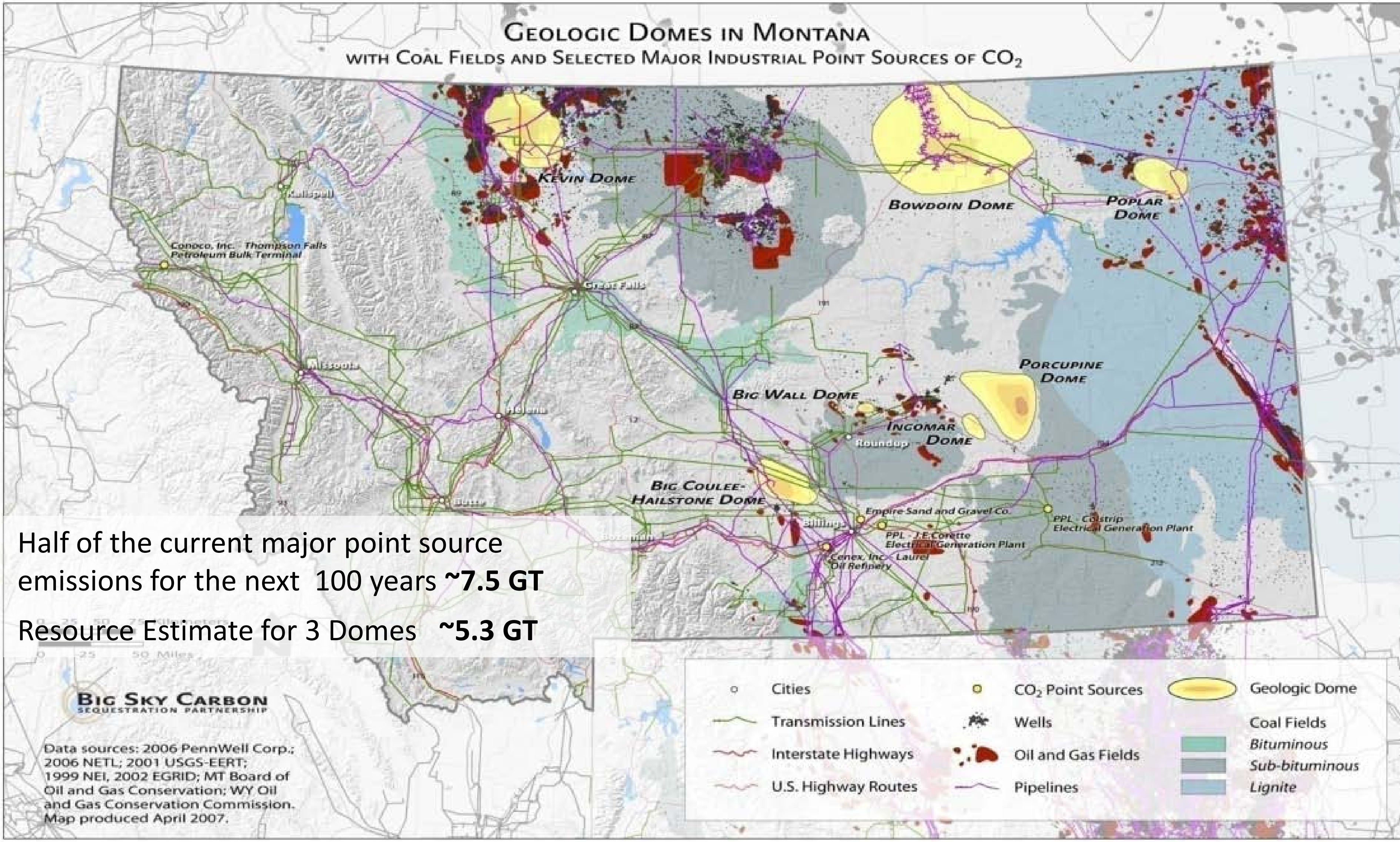
# Extra Slides

# Kevin Dome




Half of the current major point source emissions for the next 100 years **~7.5 GT**

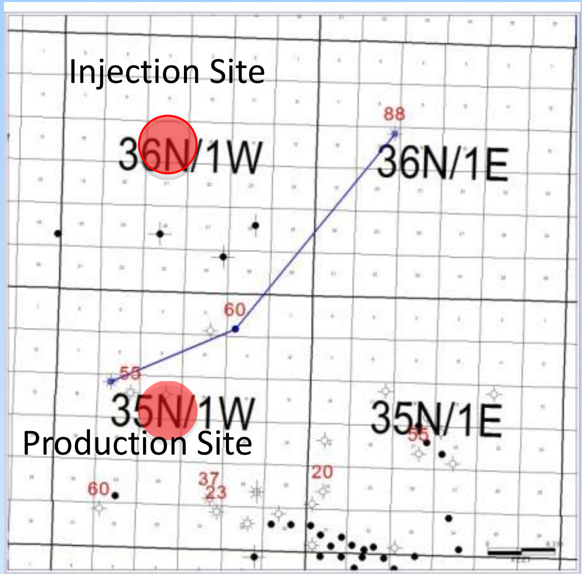
Resource Estimate for 3 Domes **~5.3 GT**

Big Sky Carbon Sequestration Partnership

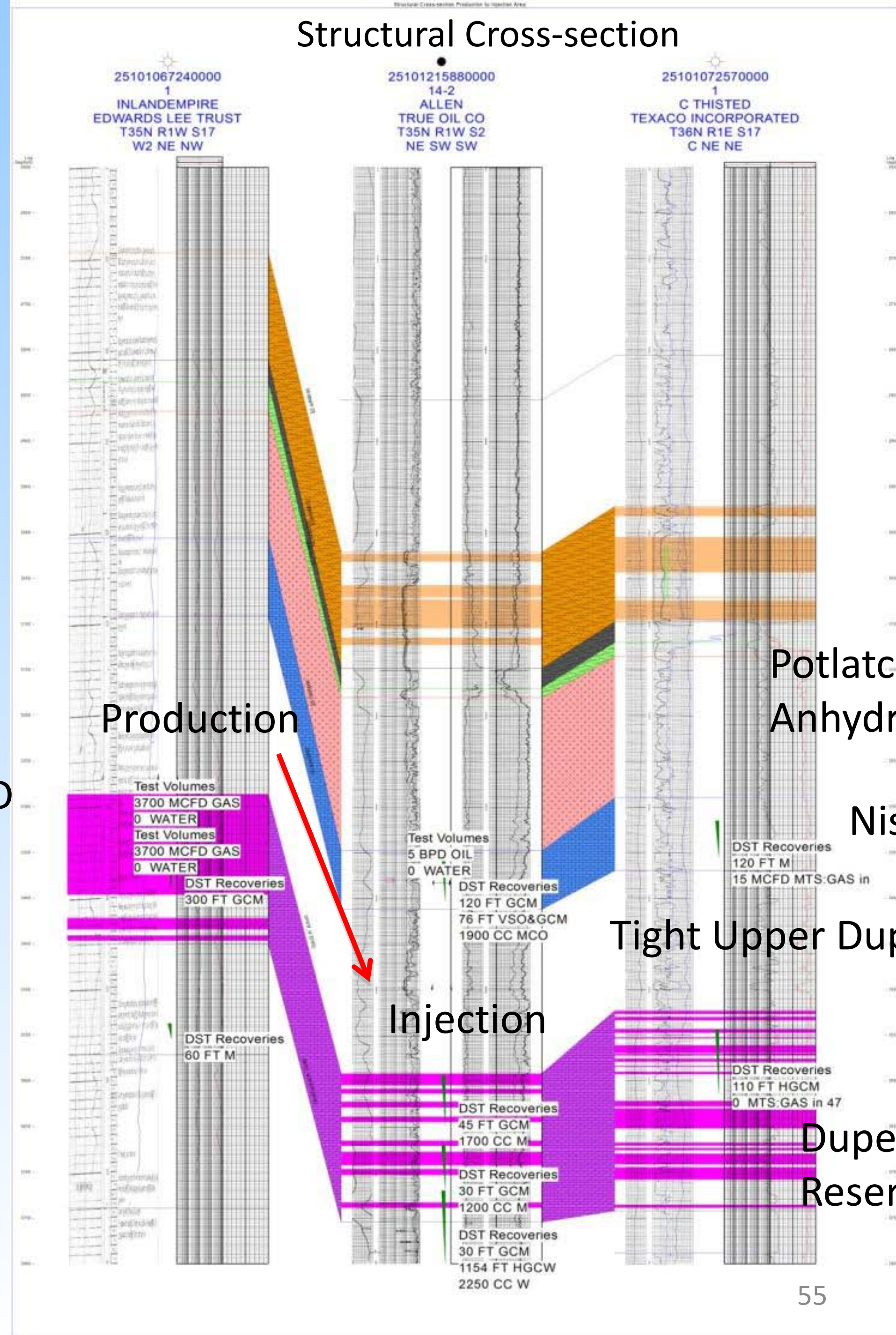
Montana State University

# Nearest Well Data

## Index Map of Cross-section




- **Production site –** offsetting well that tested 3,700 MCFGD
- **Injection site –** offsetting well in the brine aquifer on Montana State Lands shortest feasible pipeline distance

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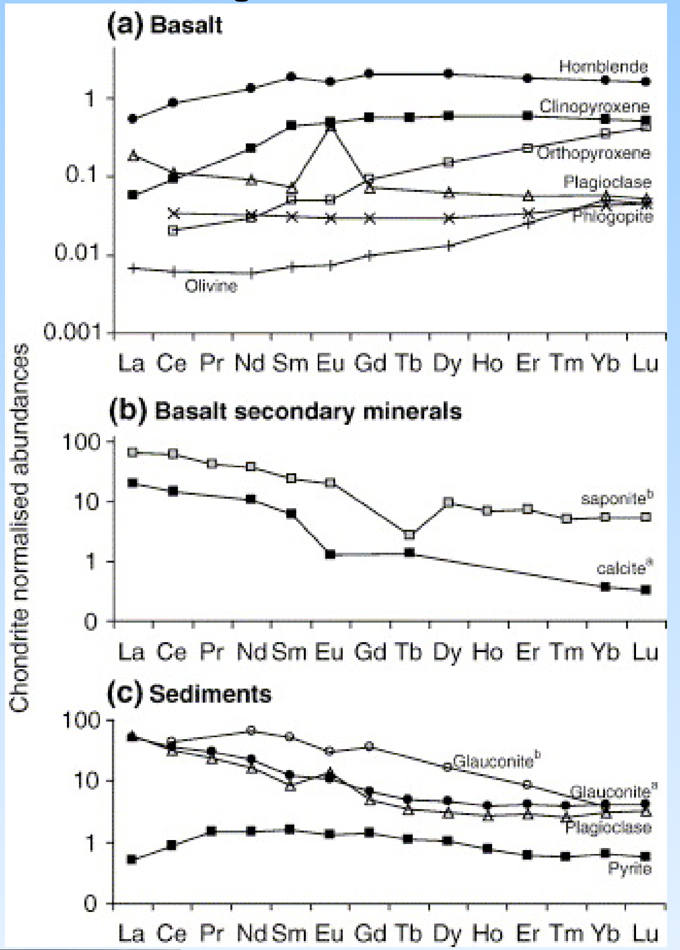
# Task 3 – Permitting and NEPA Compliance

| Permitting Activity | Responsible Agency | Time Requirements (in days) |
|---|---|---|
| **Drilling** | | |
| File Application for Permit to Drill (APD) | Montana Board of Oil and Gas (MBOG), Montana Department of Natural Resource Conservation (DNRC), Montana Department of Environmental Quality (DEQ) and the Environmental Protection Agency (EPA) | 120 |
| Drilling Plan | MBOG, DNRC, DEQ, EPA | 180 |
| Surface Use Plan of Operations (SUPO) | MBOG, DNRC | 180 |
| **Pipeline Permitting** | | |
| | MBOG, DEQ, Office of Pipeline Safety (OPS), DNRC, ROWs to be obtained from individual landowners | 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 Montana Department of Fish, Wildlife and Parks (FWP) | 120 -240 |
| **UIC Application** | | |
| Class V Injection Well | DEQ, EPA, MBOG | 120-180 |
| Monitoring Wells | MBOG | 120 |
| **Water Rights** | DEQ | 5 days – investigation only as the need for a water right is not expected |
| **Temporary Use Permit** | DNRC | 60 |
| **NEPA and MEPA – Categorical Exclusion (CX) or Environmental Assessment (EA)** | DEQ, EPA, MBOG, DNRC | 365 |
| **Record of Decision (ROD)** | EPA, MBOG, DEQ, DNRC | 180-365 |
| **Stipulations** | DNRC, FWP, MBOG, SHPO, Surface Owner | 90 |

# REE Tracer Development

**REE (La-Lu) are effective Natural Tracers in geologic systems**

- Long history of use in characterizing geologic systems and *sedimentary basin evolution*.
- REE are extremely sensitive to chemical changes imparted to brine chemistry during mineralization reactions, dissolution and transport reactions (Nelson D.T., 2005, Stetzenbach et al 2004, Wood et al 2006, McLing et al 2002, Roback and McLing 2001)
- Use as in-situ tracer for reservoir water displacement and leakage (Johannesson et al 2000).
- REE very sensitive to mineral dissolution and precipitation, parts per trillion detection with minimal sample prep
  - Samples will be collected during routine water sampling, no special tools required at Basalt and Kevin Dome Pilot.
  - Tracking $CO_2$ mass balance in CCS applications
- Laboratory Experiments useful in characterizing field collected data
  - Experiments will be carried out at INL Laboratories on reservoir rocks from both pilots





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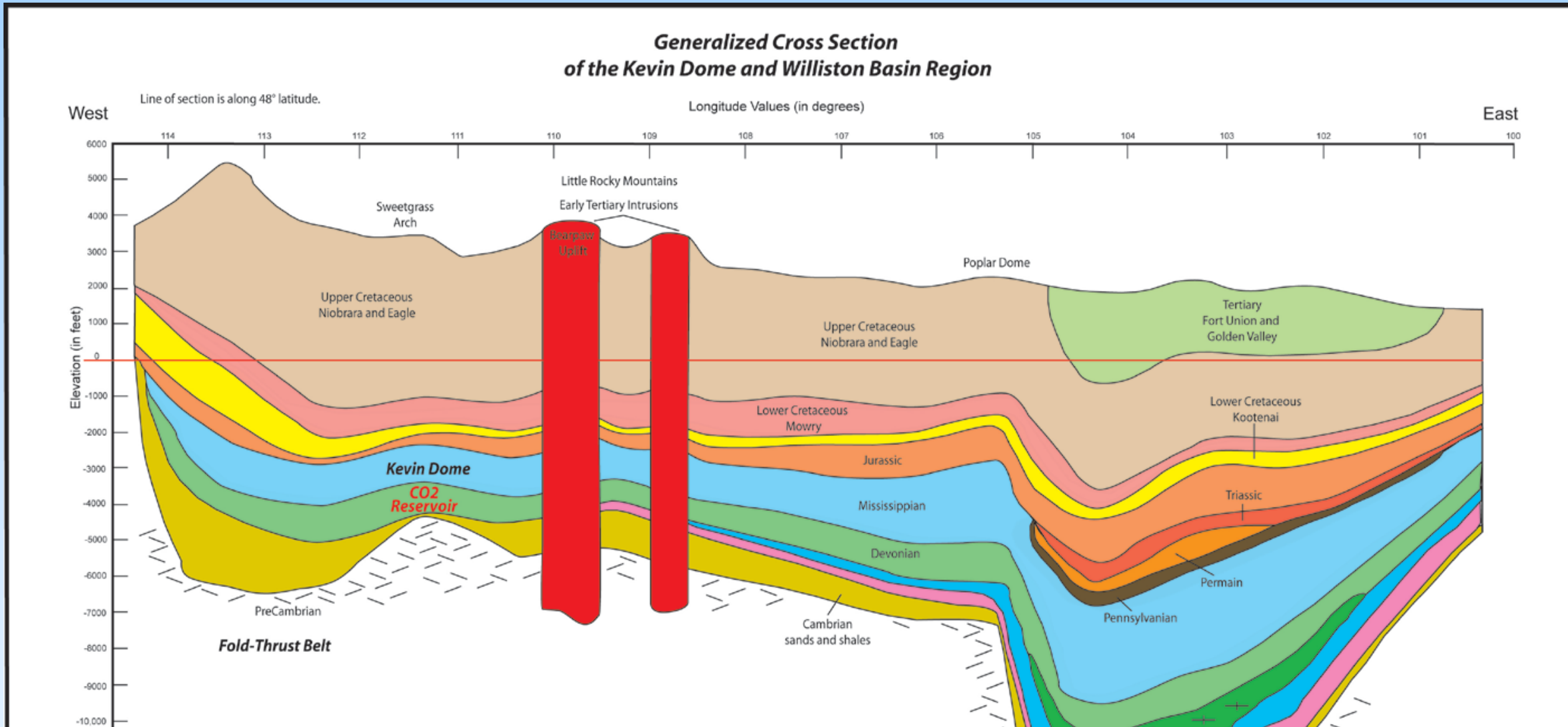
# Schematic East-West Cross Section




CO2 generated from intrusion of magma at
Sweetgrass Hills migrates to be trapped at Kevin Dome

Modified after Peterson, 1987;
Downey, 1986

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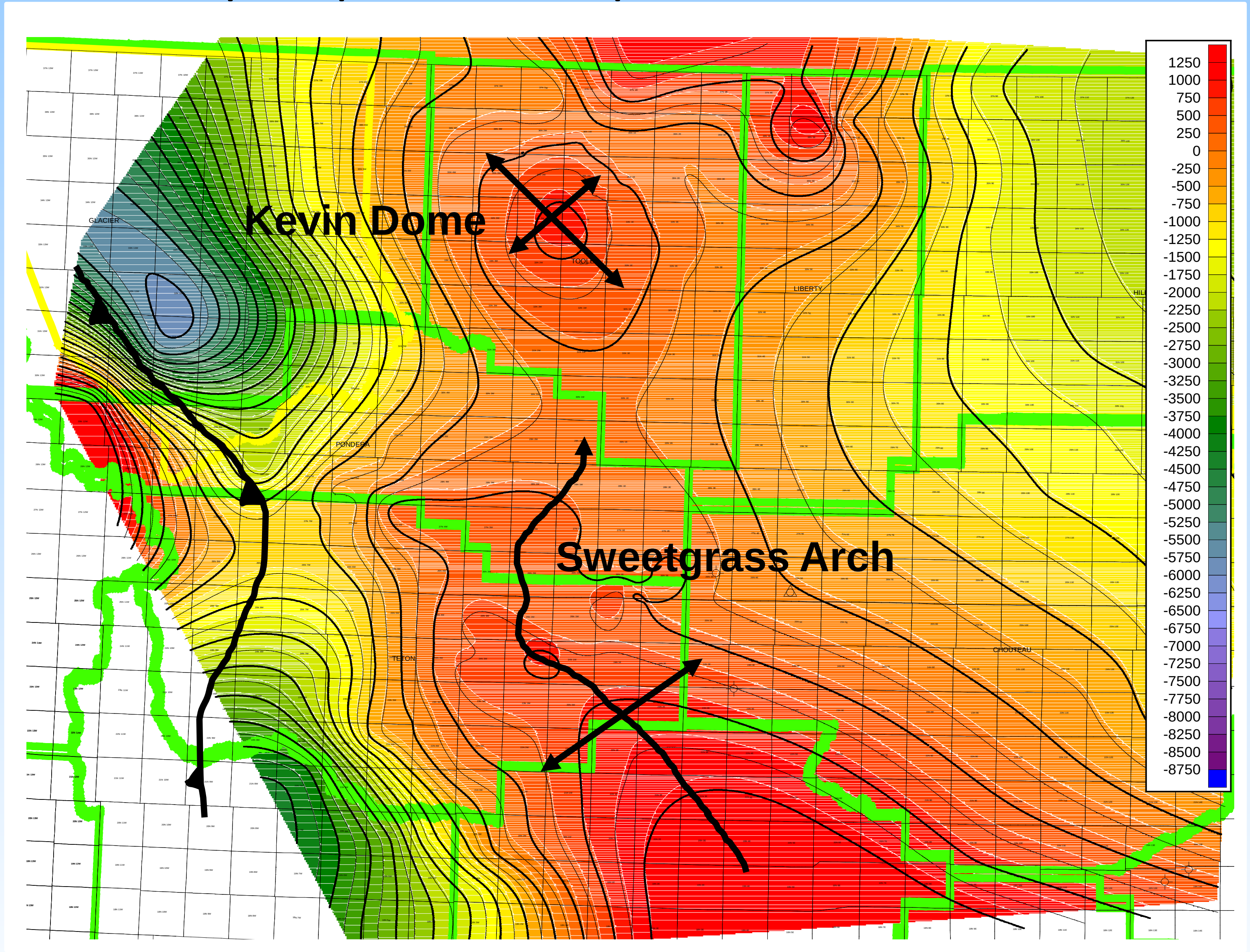
# Structure Top Duperow – Duperow Penetrations Shown



# The LBNL TOUGH Codes

**Karsten Pruess et al.**

- TOUGH: Transport Of Unsaturated Groundwater and Heat

| | |
|---|---|
| multidimensional | 1D, 2D, 3D |
| multiphase | liquid, gas, NAPL, solid ppt |
| multicomponent | water, air, $CO_2$, tracers, etc. |
| nonisothermal | heat |
| flow and transport | multiphase Darcy law |
| fractured-porous media | dual-$\phi$, dual-k, MINC, ECM |

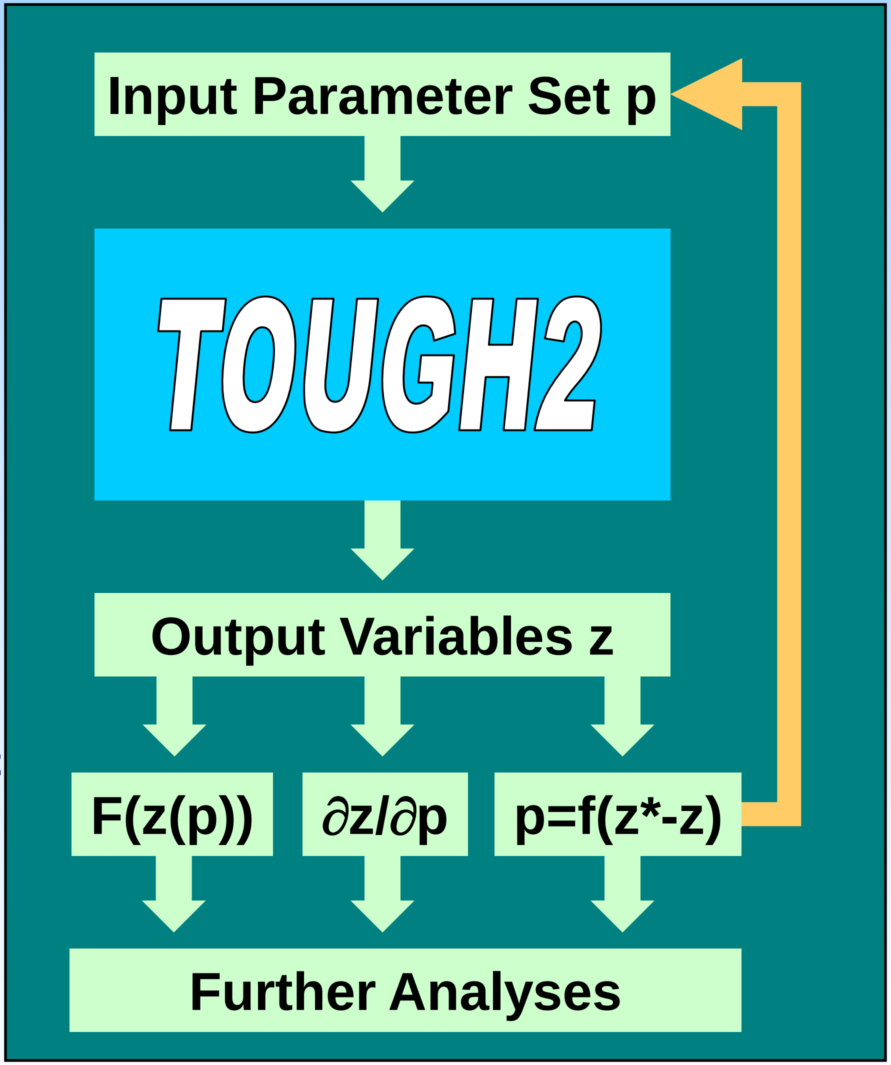
**http://esd.lbl.gov/TOUGH2/**

- **Includes a diverse set of Equation of State (EOS) modules**
- **Major variants: TOUGHREACT, TOUGH FLAC, iTOUGH2**

# iTOUGH2: Inverse Modeling

Stefan Finsterle

- Provides inverse modeling capabilities for TOUGH2
- What iTOUGH2 Does
  - Runs TOUGH2 with different parameter sets
  - Evaluates selected TOUGH2 output
- Application Modes
  - Sensitivity analysis
  - Parameter estimation by automatic model calibration
  - Uncertainty propagation
  - Uncertainty quantification

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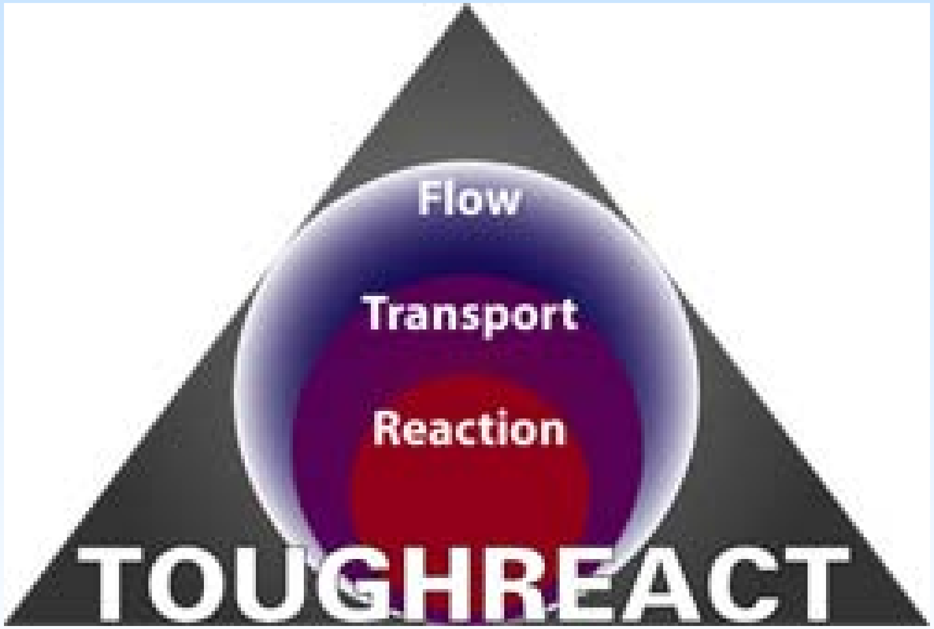
# TOUGHREACT

## Tianfu Xu, Nic Spycher, Eric Sonnenthal

- Numerical simulation program for chemically reactive non-isothermal flows of multiphase fluids in porous and fractured media
- Widely used for $CO_2$ geological sequestration:
  - Countries: Italy, France, Spain, The Netherlands, German, Denmark, Norway, UK, Australia, Japan, South Korea, China, Brazil, …
  - Companies: Exxon, Chevron, Shell, Eni, …
  - Many Universities and Institutions
- Second most requested software in ESTSC (http://www.osti.gov/estsc/mostrequested.jsp)
- Regular training courses held at Berkeley

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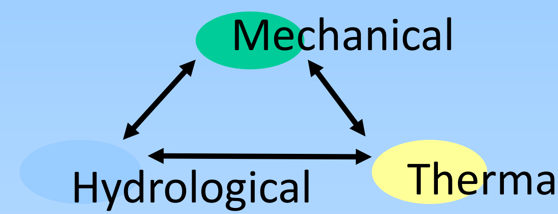
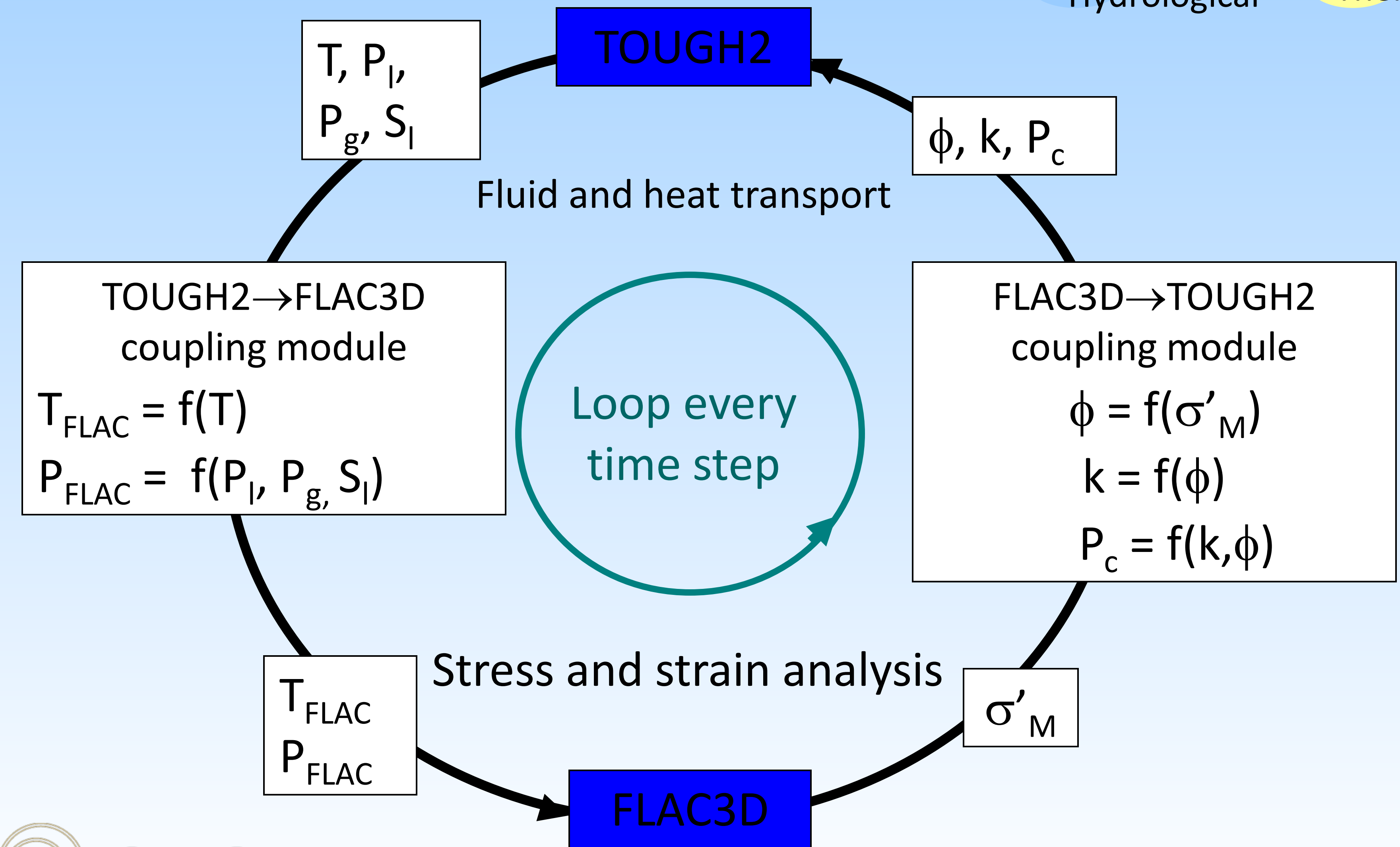
# TOUGH FLAC

**Jonny Rutqvist**



# MVA Needs Quantification

- Distinguish stored $CO_2$ from natural $CO_2$ sources

**Radiocarbon Tagging Method**

- Labeling the injected $CO_2$ with an isotopic tracer

$$^{12}CO_2 \text{ -> } ^{14}CO_2$$

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# Carbon-14 ($^{14}C$) as a Novel MVA Tool

**Carbon Isotopes**

Stable: $^{12}C$ - 98.93%

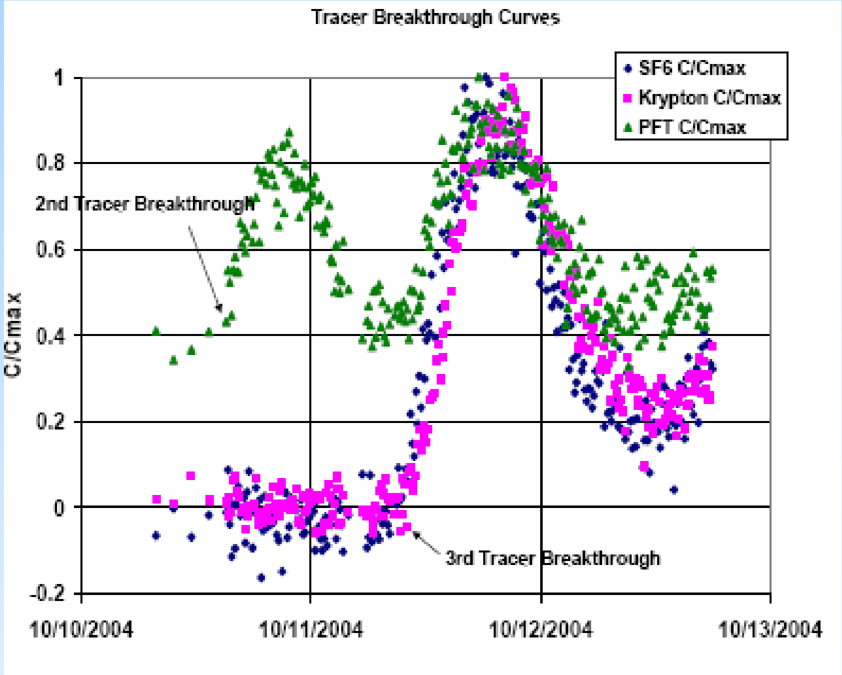
$^{13}C$ - 1.07% $^{13}C/^{12}C = 0.01$

**Radioactive: $^{14}C$ 1ppt $^{14}C/^{12}C = 1.3 \times 10^{-12}$**

half-life of about 5730 years

- deep reservoirs have no or very small amounts of $^{14}C$
- $^{14}C$ is a smart tracer for:
  - reaction processes (dissolution – precipitation)
  - biogeochemical processes
  - mixing processes in combination with conservative tracers
  - inventory of stored $CO_2$
- Tagging of 1Gt $CO_2$ requires 320 grams of pure $^{14}C$

# Conservative Tracers for Tracking Plumes
# $SF_6$, $SF_5CF_3$, PFTs




Source: Freifeld et al. (2005)

- allows plume tracking
- allows leakage detection
- only technique to monitor solubility and mineral trapping
- requires well penetration and perforation, sampling apparatus

US DOE and NETL

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**Outreach Director**
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Barb Bunge

**Project Manager**
Lindsey Tollefson

**Project Manager**
New Hire

**Task 3: Permitting & NEPA Compliance**
Bison Eng.

**Task 5: Well Drilling & Completion**
Altamont Energy

**Task 6: Infrastructure Development**
Altamont Energy

**Task 7: $CO_2$ Procurement**
Vecta, PM

**Task 8: Transportation & Injection**
Altamont Energy

**Task 10: Site Closure**
Vecta, PM

**Task 1: Regional Characterization**
RC - Fairweather
Econ - Antle
Terrest - Brown

**Task 2: Outreach & Education**
Outreach Dir

**Task 4: Site Characterization & Modeling**

**Task 9: Operational Monitoring & Modeling**

**Task 11: Post Injection Modeling & Monitoring**

**Task 12: Project Assessment**

Geostatic Model – Merri Trigilio, MSU
Simulation Model – Curt Oldenburg, LBNL
Seismic – Bryan DeVault, Vecta
Risk Modeling – Bill Carey, LANL
Core Studies – Colin Shaw, MSU
Geochemical Studies – Jeurg Matter, Columbia, Travis McLing, INL

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