The Kevin Dome Carbon Storage Project

Lee Spangler

Director, Big Sky Regional Carbon Sequestration Partnership

Montana State University

BIG SKY CARBON SEQUESTRATION PARTNERSHIP

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Acknowledgments

- US Department of Energy
- Altamont Oil & Gas, Inc.
- Columbia University & Barnard College
- Idaho National Laboratory
- Los Alamos National Laboratory
- Lawrence Berkeley National Laboratory
- Schlumberger Carbon Services
- SWCA Environmental Consultants
- Vecta Oil and Gas, Ltd.
- Washington State University

Regional Carbon Sequestration Partnerships

"Developing the Infrastructure for Wide Scale Deployment"

The Plains CO_2 Reduction Partnership PCOR

MGSC

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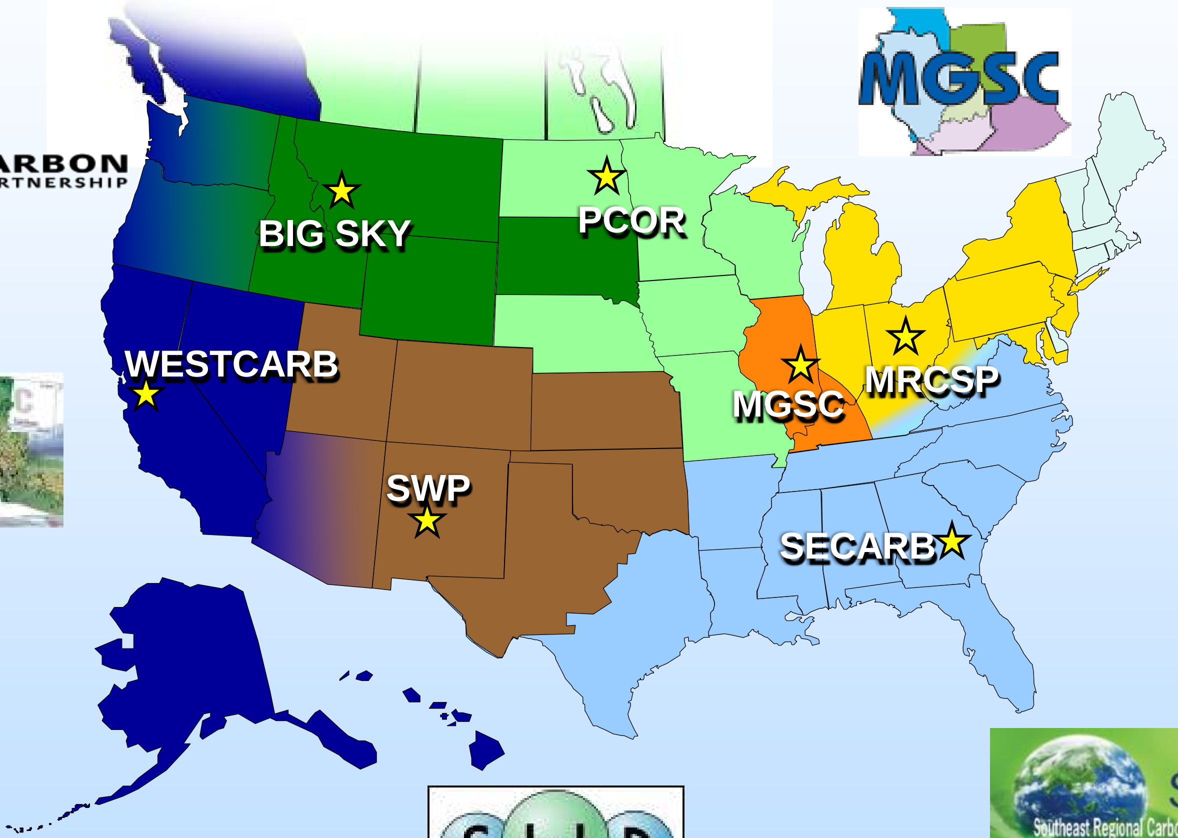


MRCSP MIDWEST REGIONAL CARBON SEQUESTRATION PARTNERSHIP

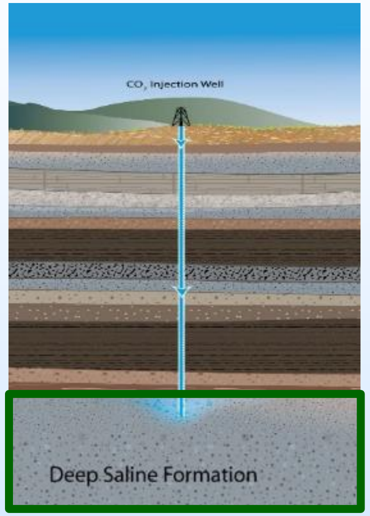
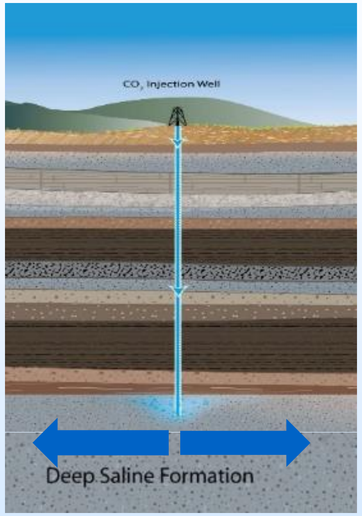
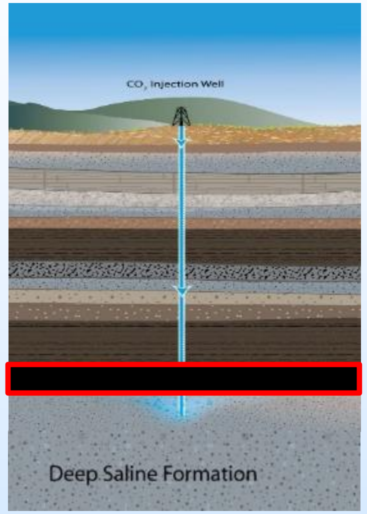
West Coast Regional Carbon Sequestration Partnership westcarb.org

SWP Southwest Partnership CO_2 Sequestration

SECARB Southeast Regional Carbon Sequestration Partnership

43 States, 4 Canadian Provinces over 350 organizations including NGOs

Requirements for Storage

Capacity	Injectivity	Storage Security
		
Formation thickness Areal extent Porosity Compartment size Water Quality	Permeability Compartment size Geochemistry Mechanical properties	**Seal impermeability** **Seal continuity** Seal thickness Geochemistry Mechanical Properties

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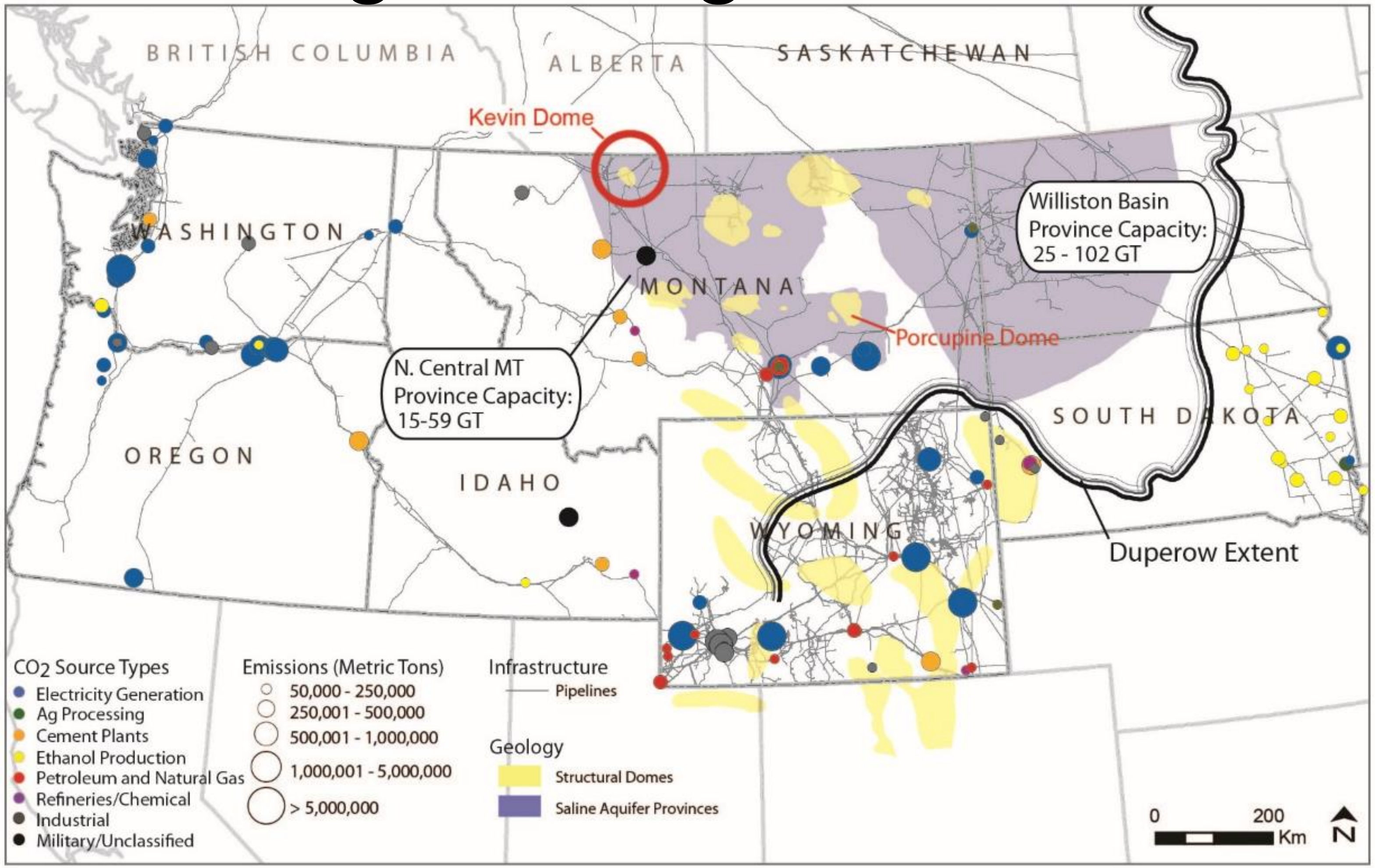
The Big Sky Carbon Sequestration Partnership
What We Do

- Regional Geologic Characterization
- Outreach
  - General Public
  - NGOs, Environmental Groups
  - Decision Makers, Legislative Bodies
- Pilot , Demonstration, and Commercial Projects
  - Site Characterization
  - Three - Dimensional model development
  - Flow modeling
  - Monitoring
  - Risk Assessment
- Contribute to Best Practices Documents
- Provide an “Expert Network” on CCS

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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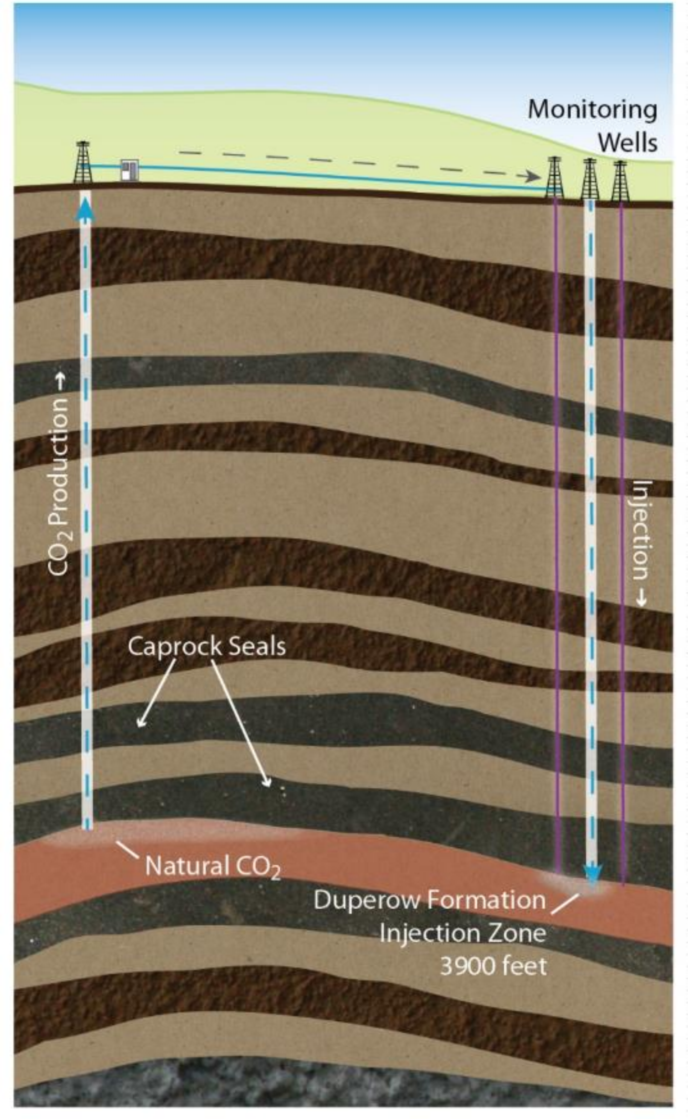
Montana State University

Project Overview

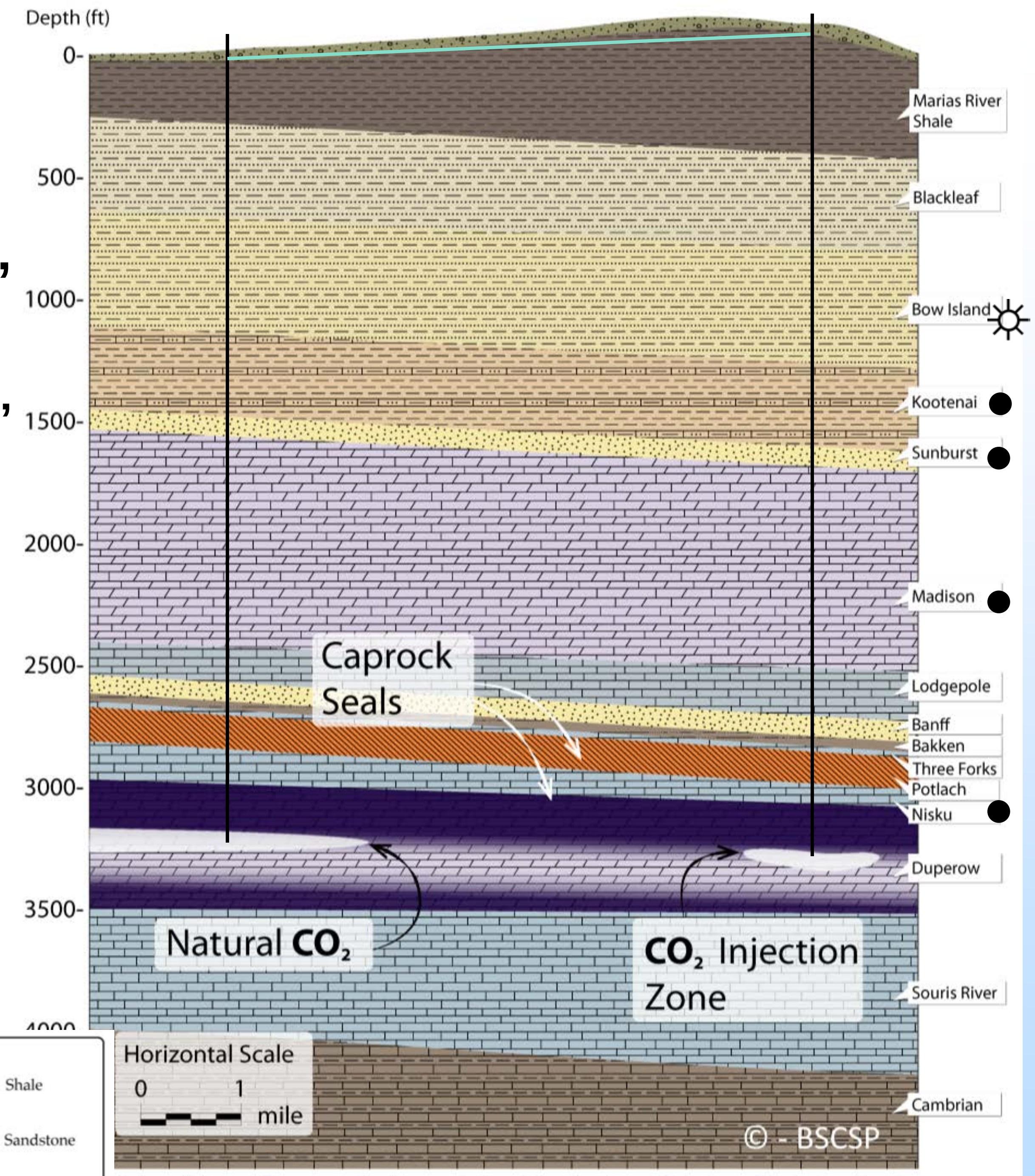
- Permitting & Public Outreach
- Site Characterization
- Infrastructure Development
  - 1 Production test well
  - 1 Injection Well,
  - 3 Monitoring Wells,
  - Pipelines Compressor
- Injection Operations – 4 years
- Monitoring & Modeling
- Site Closure

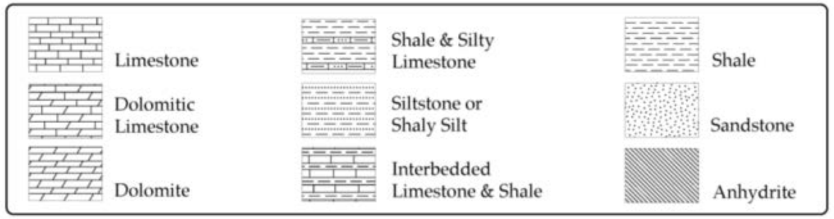
- $65M DOE, $18M Cost Share



Kevin Dome

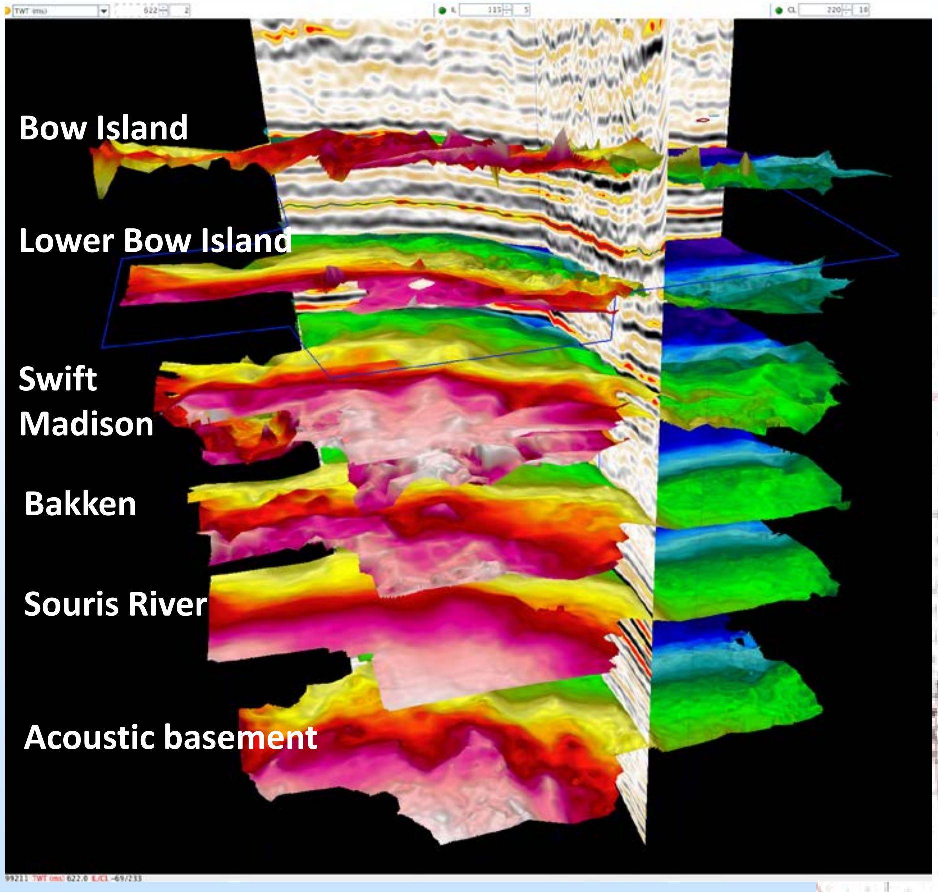
- CO_2 in middle Duperow
- Two "gold standard" seals
  - Upper Duperow ~200' tight carbonates and anhydites
  - Caprock~ 150' Anhydrite Caprock
- Multiple secondary, tertiary Seals



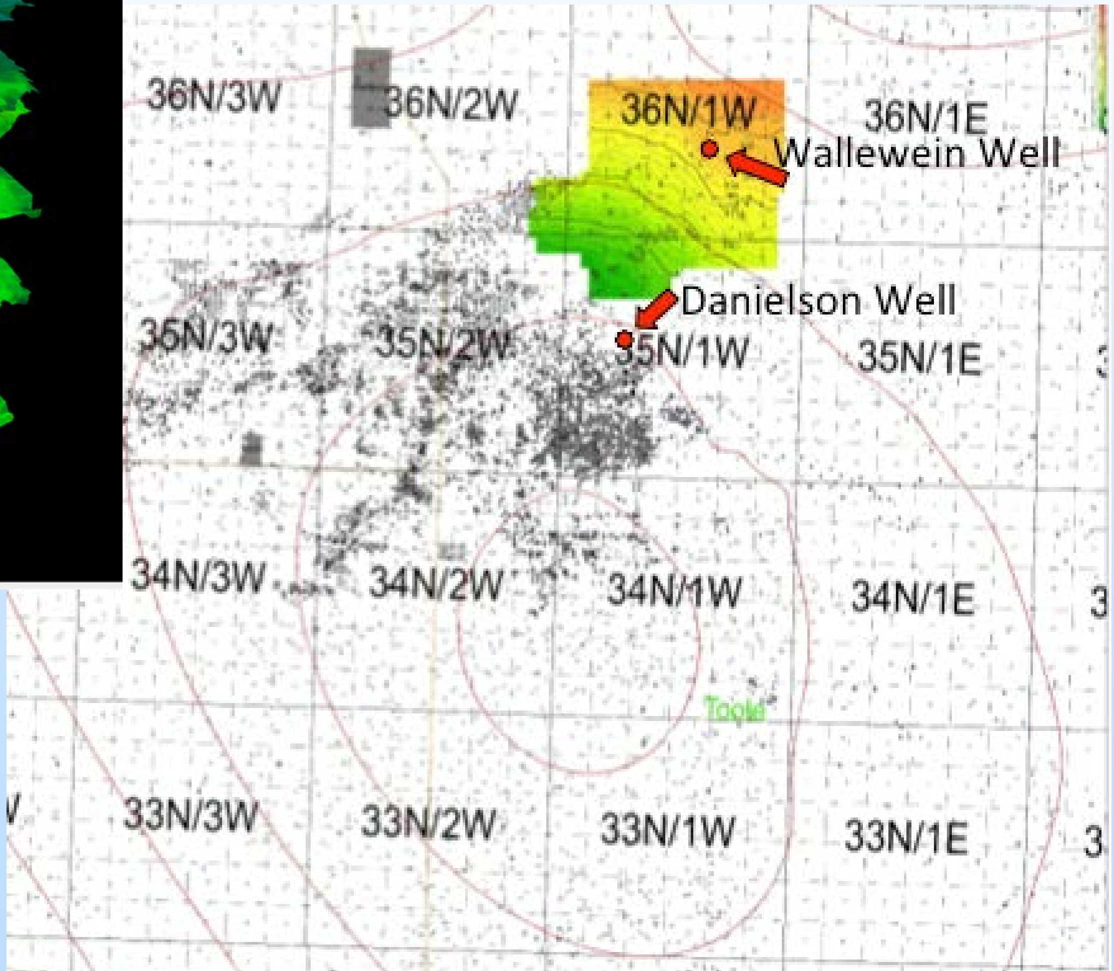


claimer: This graphic is a generalized representation of the subsurface at Kevin Dome. The horizontal and tical scale are independent of one another to fit view on a single page. Surface infrastructure not to scale.

Seismic Structural Data

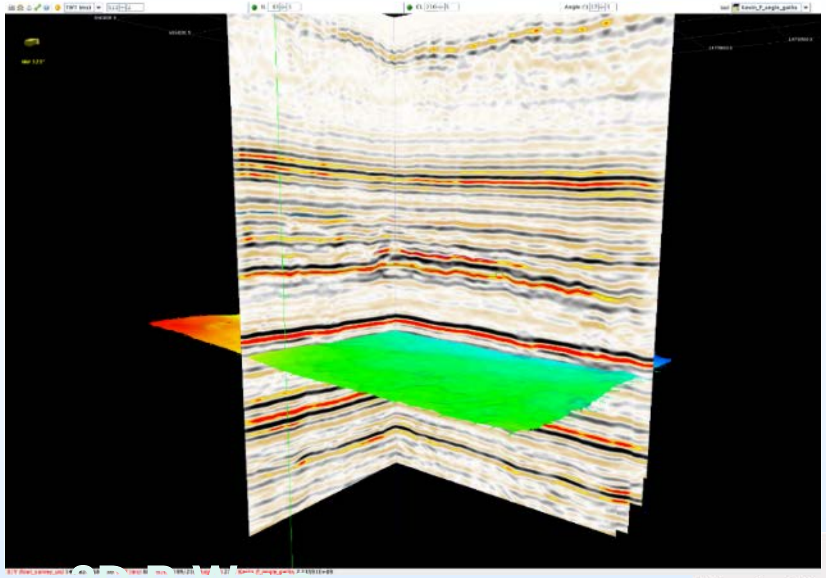


Structure Top Duperow from Well Control and Structure Top Bakken Shale from Seismic

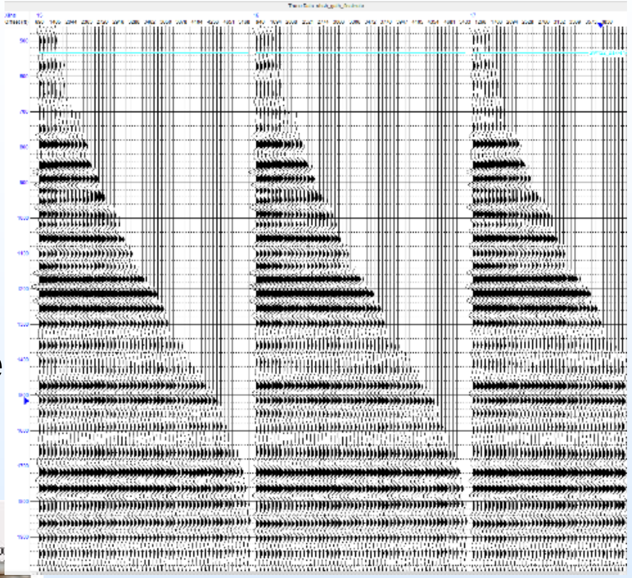


Structural surfaces from Shear Wave (SH) Seismic BSCSP Kevin Dome

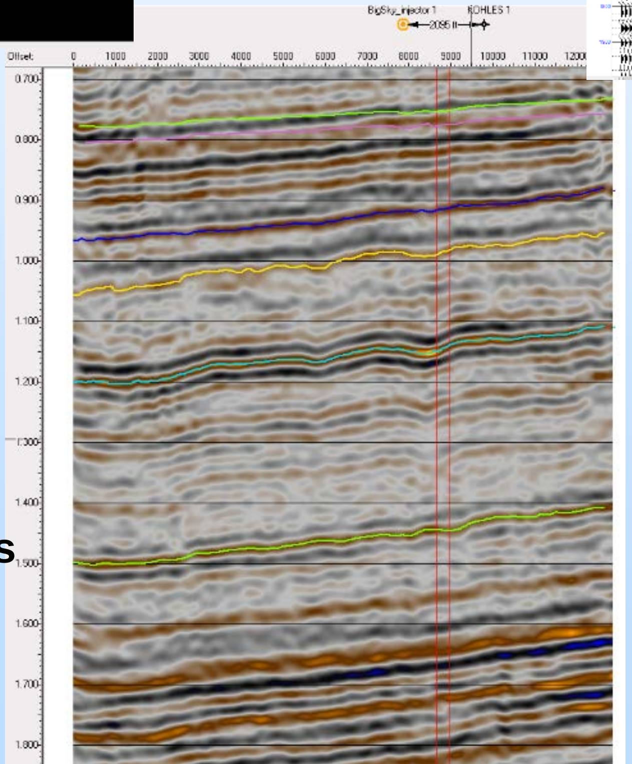
BSCSP Seismic Monitoring Program



In addition to the 3D, 9C surface seismic shown, Multicomponent VSP and X-well seismic with a state-of-the-art orbital source are planned



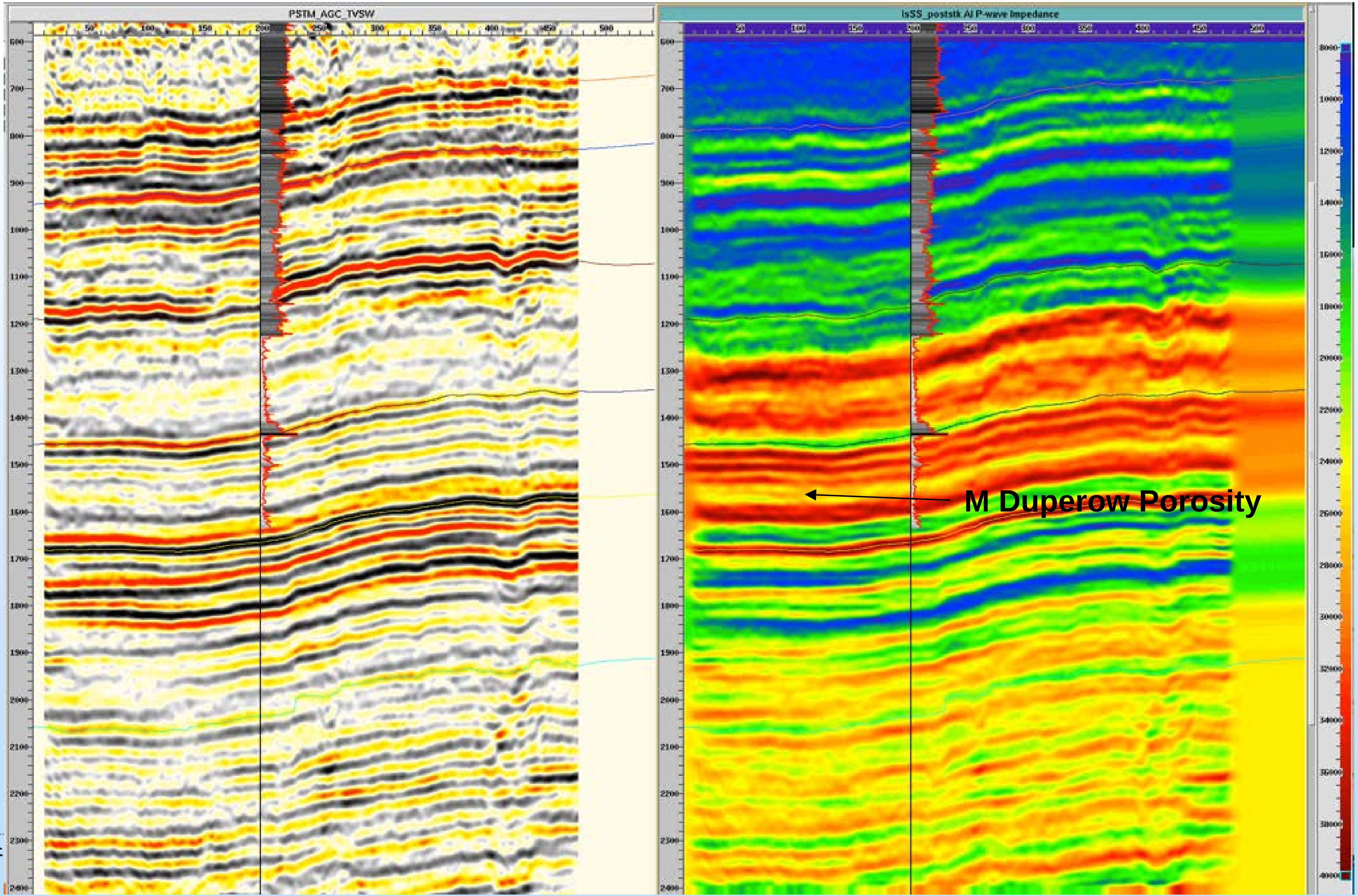
BSCSP Partner, Vecta has the only shear wave vibroseis trucks in North America.



Very good S/N in large offset S_H data may allow inversion for density and separation of rigidity and density contribution to seismic signal. In turn, this may lead to deeper understanding of seismic response to supercritical CO_2

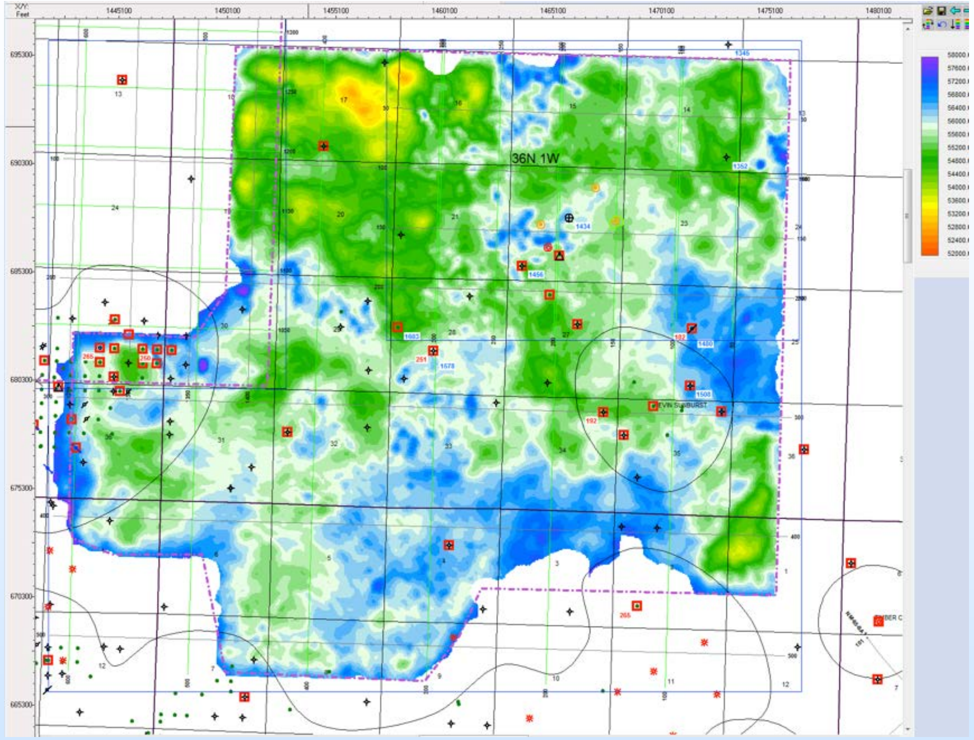
BSCSP Seismic Monitoring Program

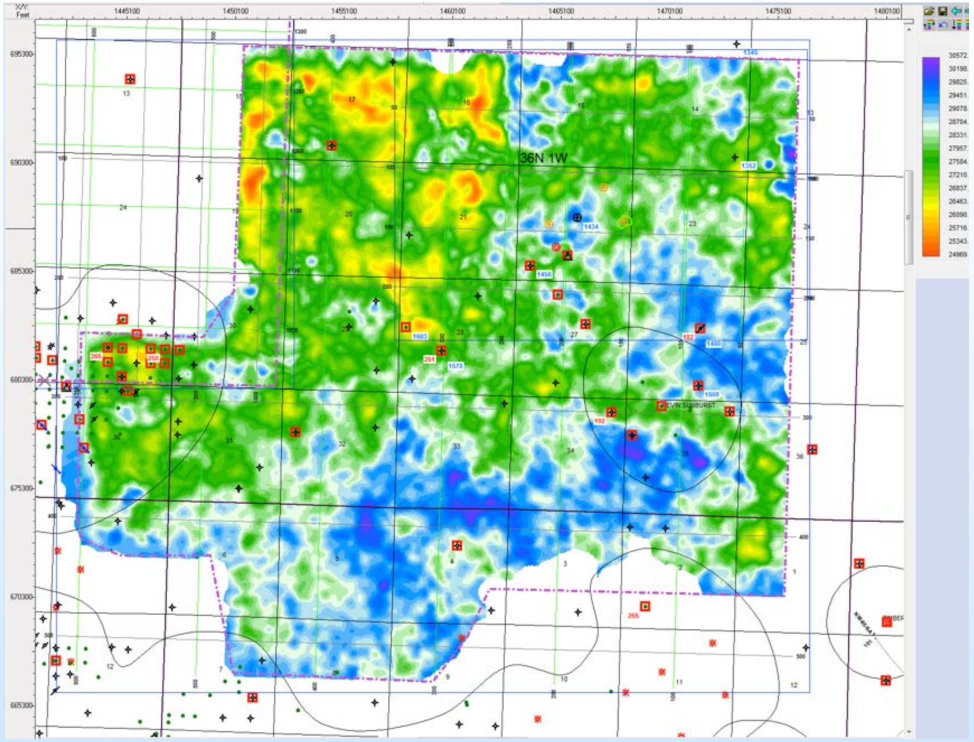
Poststack P and SH inversion IsSS with Wallewein GR



BSCSP Seismic Monitoring Program

Vecta Oil & Gas Ltd.





Ip at Middle Duperow porosity zone

Joint inversion IsPP shows larger variation at Duperow

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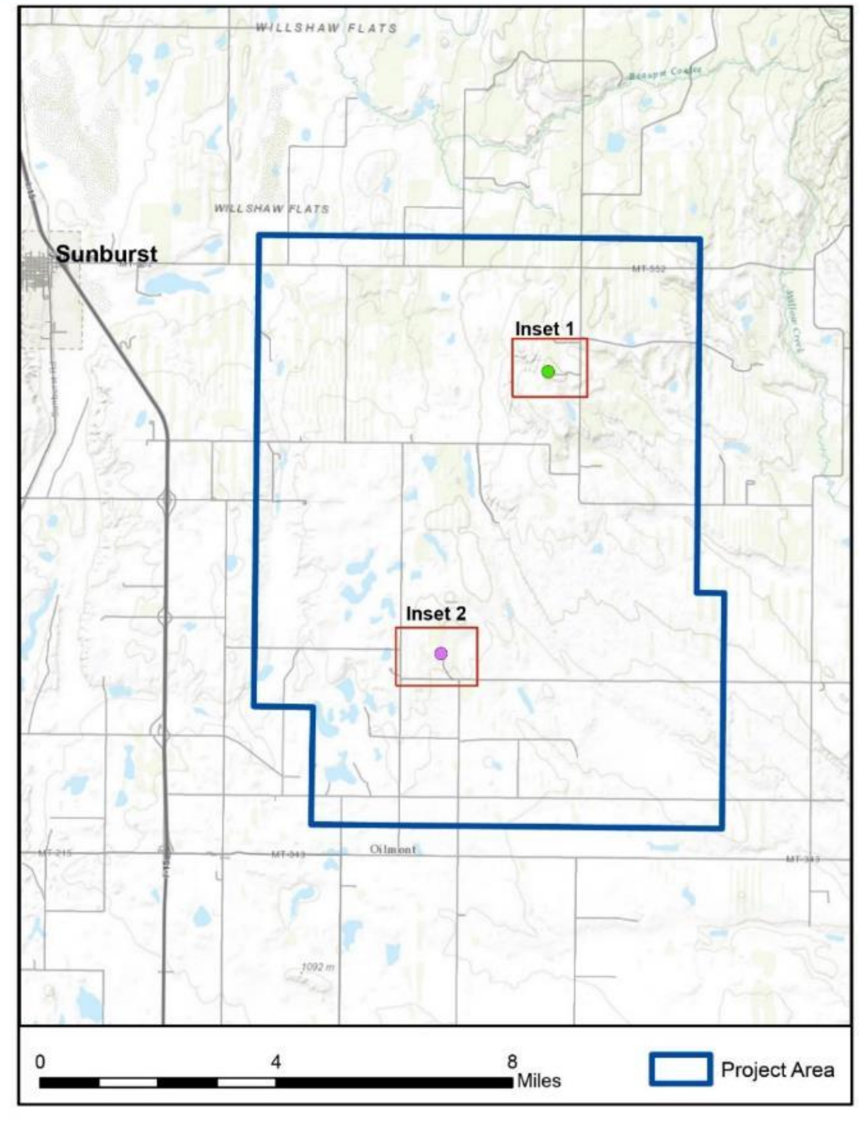
Well Locations



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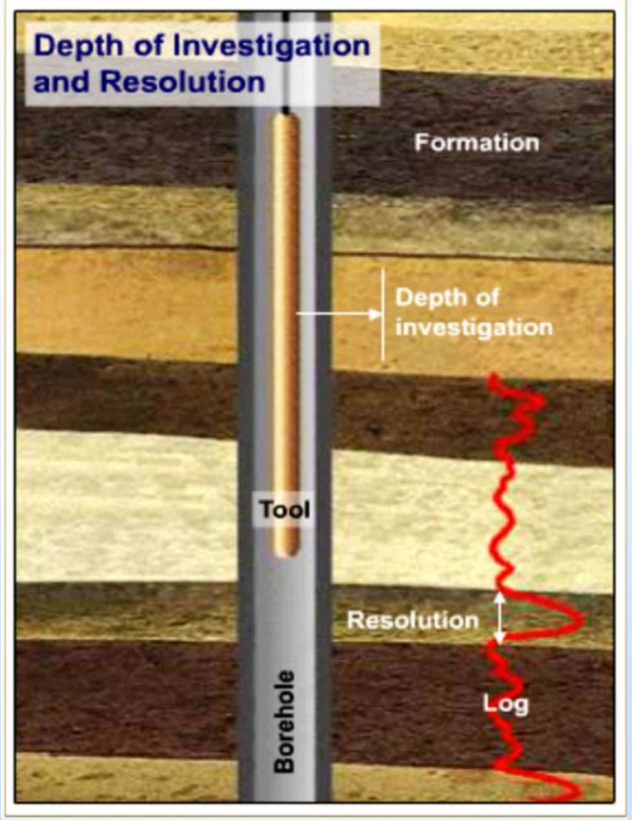
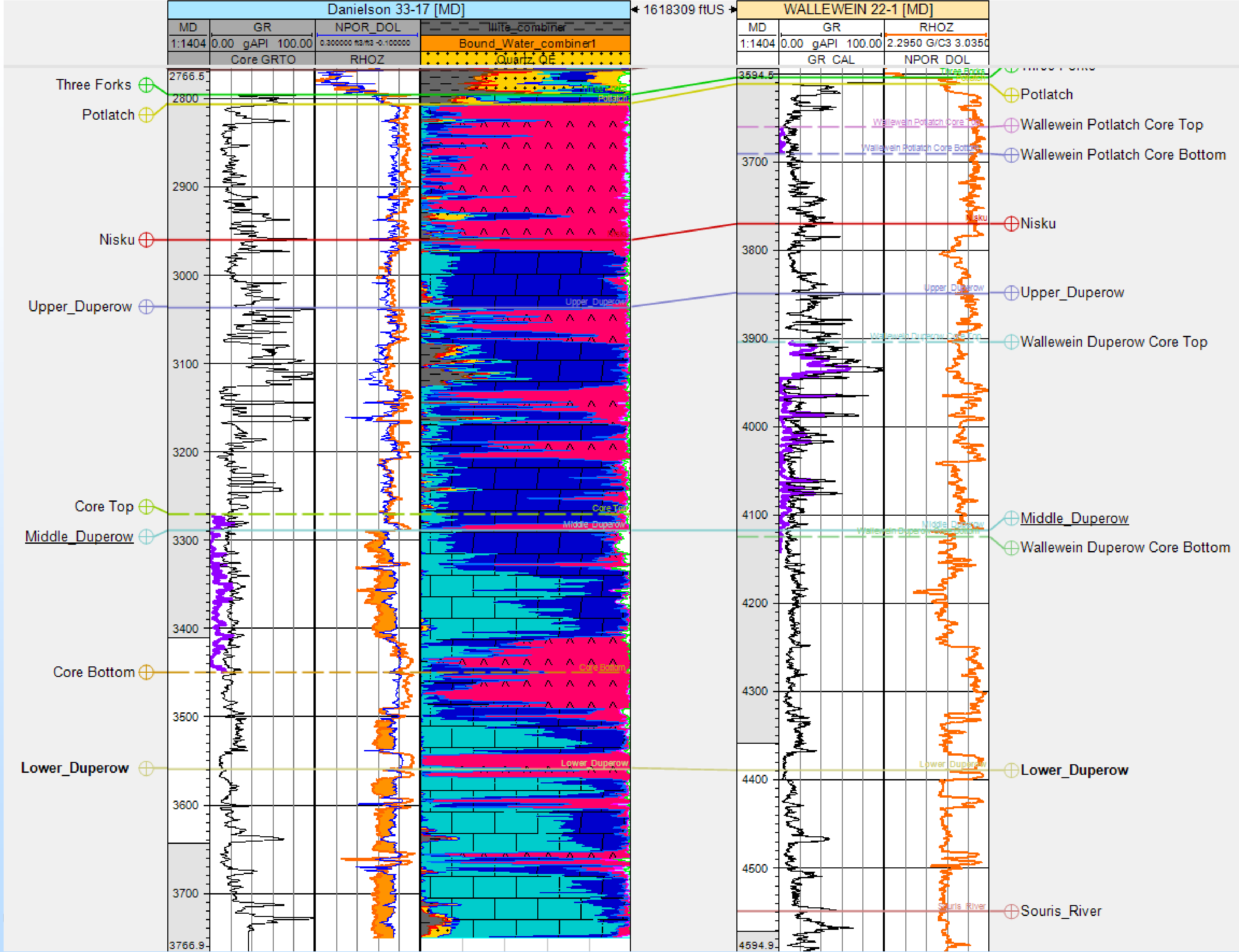
Geophysical Characterization & Monitoring: Well Logging



Logs	Wells			
	1st Prod	Inj	Mon	All
Downhole P & T	Cont.	Cont.	Cont.	Cont.
Gamma Ray	Init	Init	Init	Init
Resistivity	Init	Init	Init	Init
Porosity	Init	Init	Init	Init
Density	Init	Init	Init	Init
Caliper	Init	Init	Init	Init
P&S Sonic	Init	Init	Init	Init
Sonic Scanner	Init	Init	Init	
Isolation Scan	Init	Init	Init	
FMI	Init	Init	Init	
NMR	Init	Init	Init	
Natural Gamma	Init	Init	Init	
Elemental Spec	Init	Init	Init	
Cement Eval	Init	Init	Init	Init
Pulsed Neutron	Init	Annual	Annual/ 2 Annual	Init



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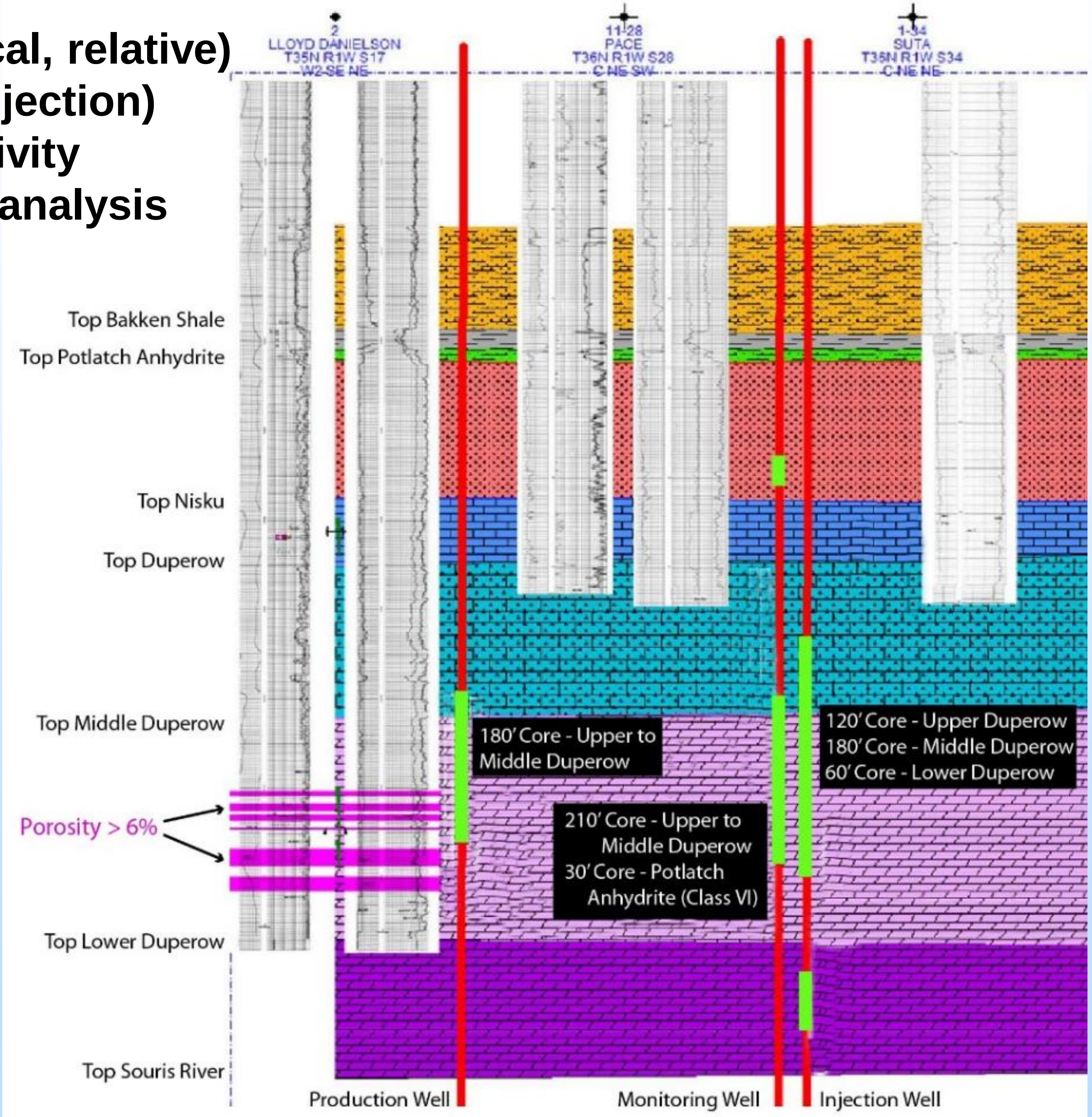
Core Plan – Intervals and Analyses

Porosity
Permeability (horizontal, vertical, relative)
Capillary pressure (mercury injection)
Core flood, geochemical reactivity
Seismic properties, anisotropy analysis
Tight rock analysis)
Petrology/Petrography
Bulk XRD
Powder XRD
NMR calibration
SEM/EDS
Micro-CT imaging
Ductility and rock strength
Bulk composition XRF
BET surface area
Core spectral gamma ray
Whole rock analysis, REE
XrF, ERD
Thin section analysis
Carbon isotopes



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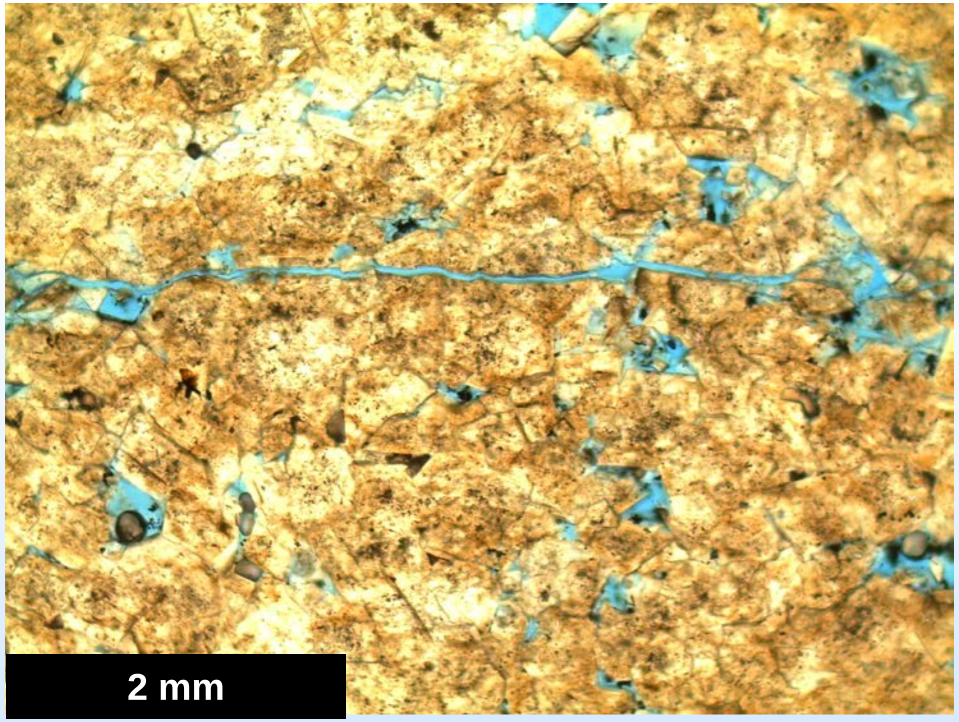
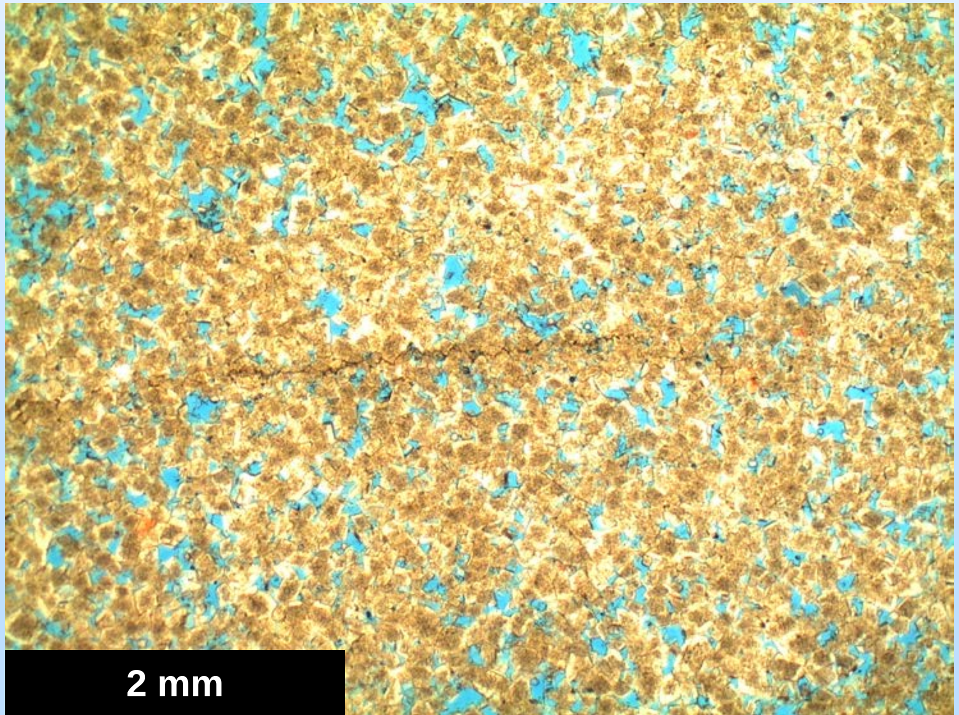
Middle Duperow – Top of Porosity Zone

Thin Sections – Dual Porosity



Thin Sections show both intergrain matrix porosity and microfracture porosity resulting in good permeability



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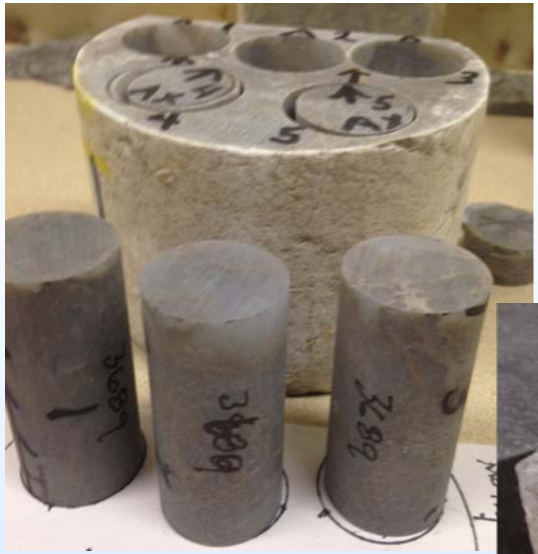
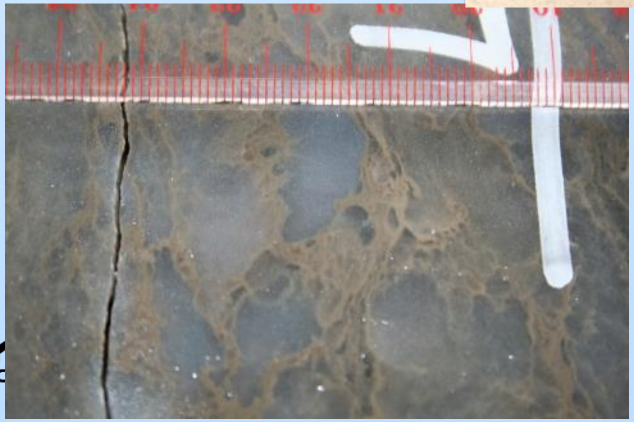
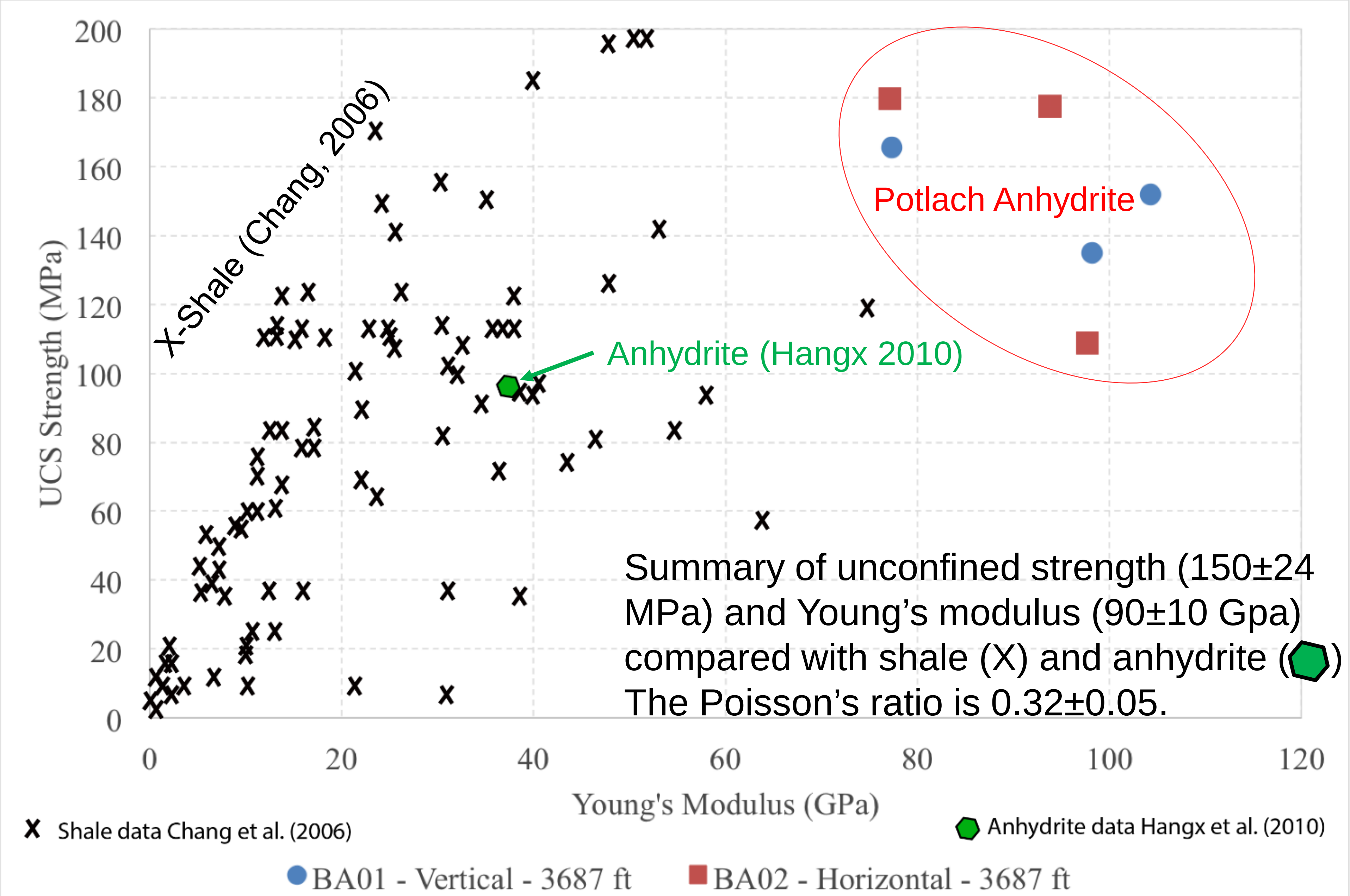
Caprock Geomechanical Tests





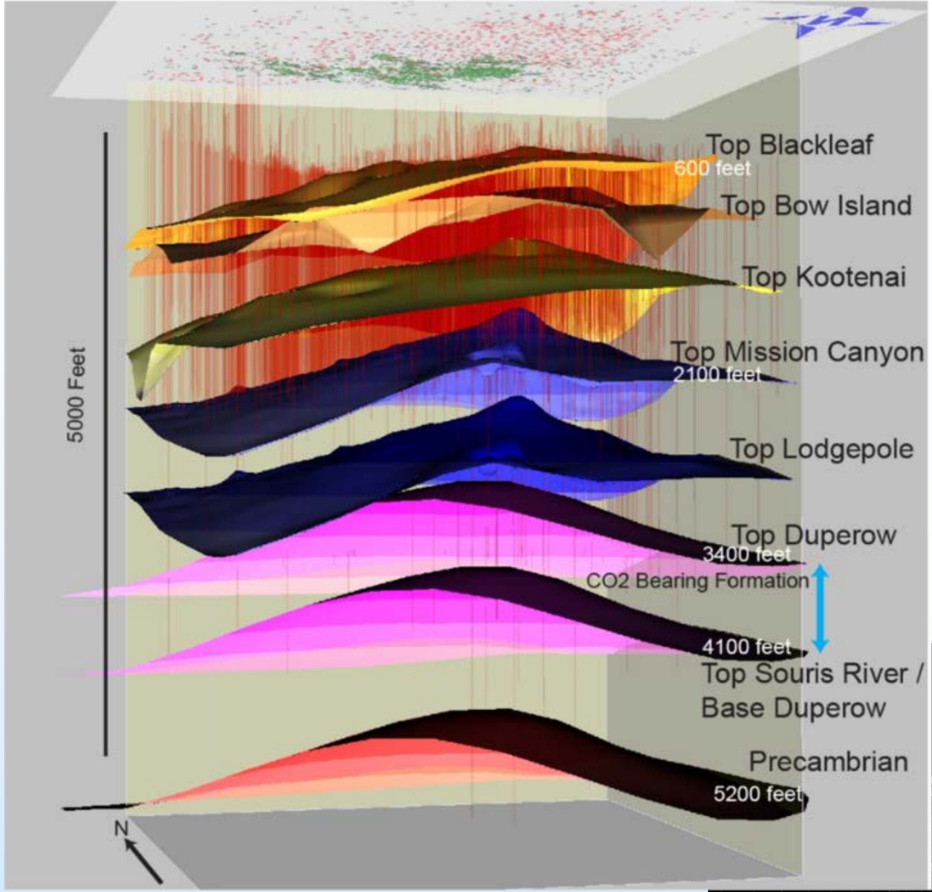
- **Potlatch Anhydrite**
- **3687'-depth of the Wallawein well**
- **Sample density 2.5 - 2.83 g/cm^3(close to the theoretical density of anhydrite (2.97 g/cm^3 indicating nearly pure anhydrite with very little porosity.)**
- **Single crystals of anhydrite appear to be as large as 1-3 cm**

Caprock Geomechanical Tests



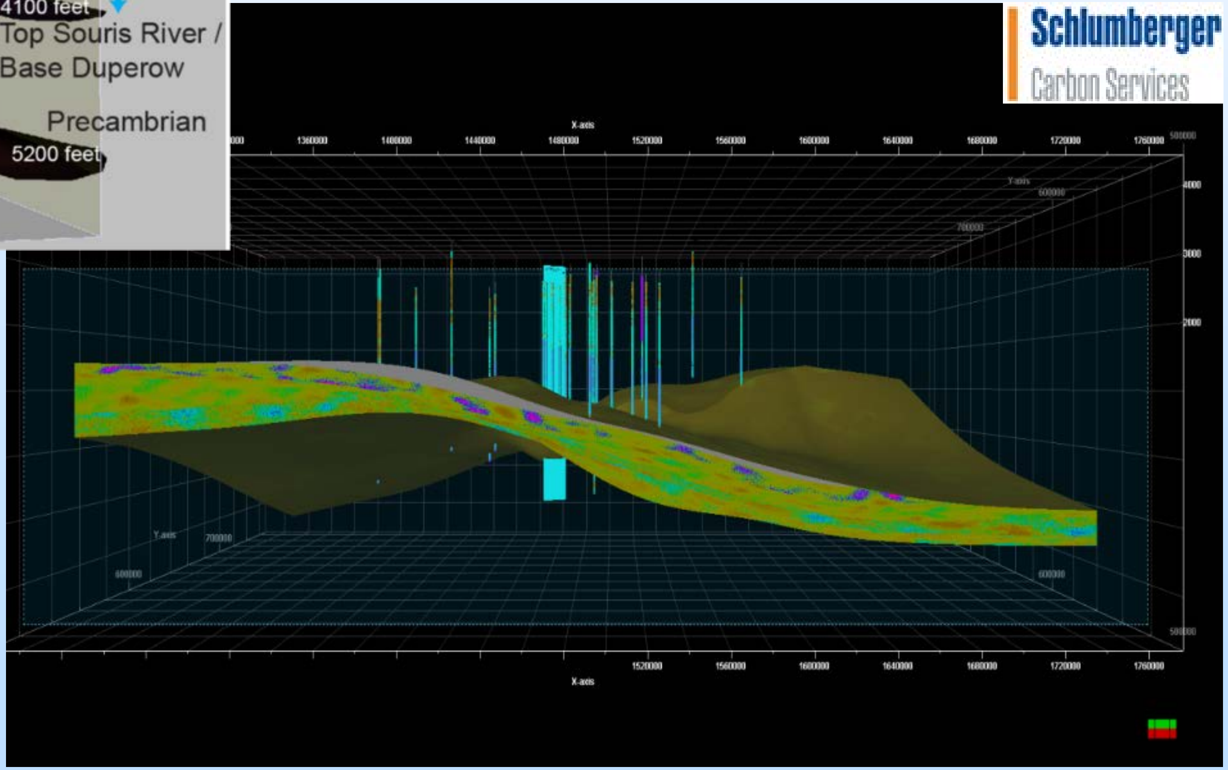
Summary of unconfined strength (150±24 MPa) and Young's modulus (90±10 Gpa) compared with shale (X) and anhydrite (⬢) The Poisson's ratio is 0.32±0.05.

Static Model



Petra – Works with IHS well log database. Use ~1000 wells to pick formation tops. Good for structural information. Export info to Petrel.

Petrel – Incorporate logs, petro-physical properties (18 wells in injection zone), existing 2D seismic and BSCSP acquired 3D seismic. Export cellular model info for flow modeling.



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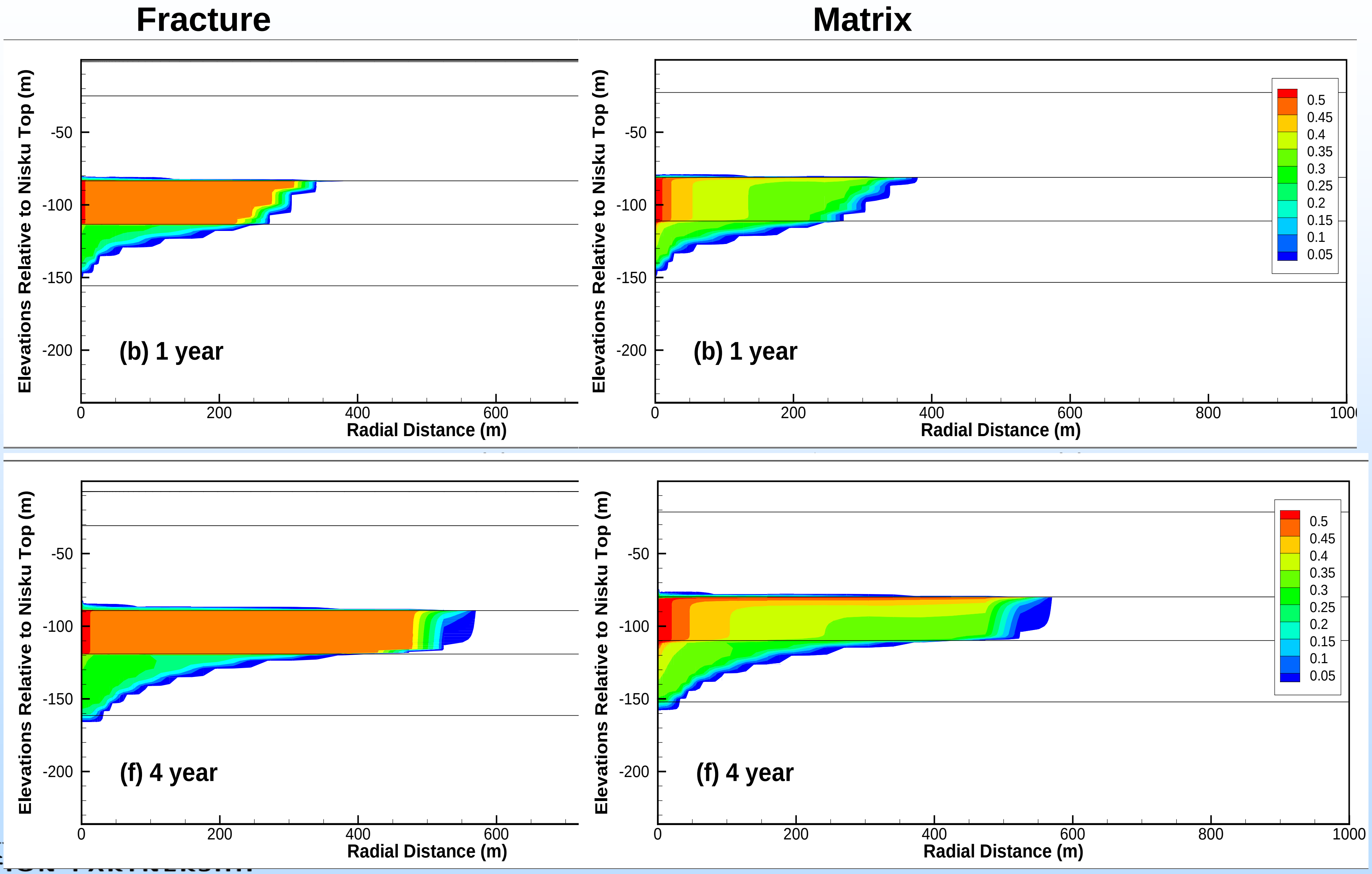
MINC Simulated CO_2 Plumes



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BERKELEY LAB

Accomplishments to Date

Regional Characterization

- Contributions to Carbon Atlas
- Evaluating EOR opportunities

Outreach

- Multiple community meetings, individual landowner meetings, website, newsletters, etc.
- Significant interest in collaboration

Permitting

- NEPA EA complete
- Landowner permits in place
- Permit database tool

Risk Management

- FEPS & Scenarios complete
- Database created
- Preliminary probabilistic modeling preformed

Site Characterization

- Kevin Atlas created with surface and subsurface data incorporated
- Over 32 sq. mi. 3D, 9C seismic shot
- Static geologic model created
  - Hundreds of wells for tops, 32 logs digitized for geophysical parameters, 2D seismic, 3D, 9C seismic
- Initial flow modeling performed
  - Injection & production regions, sensitivity analysis, reactive transport
- First two wells drilled
  - Core acquired, analyzed
  - Logs acquired
  - Seismic being tied to wells
  - Well tests performed
- Baseline assurance monitoring initiated
  - Three water sampling campaigns
  - Soil flux (chambers, eddy covariance)
  - Hyperspectral Imaging flight
  - LIDAR

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ZERT Controlled Release Experiment

Lee H. Spangler
Director, ZERT and The Energy Research Institute
Montana State University

Zero Emissions Research & Technology

A US Department of Energy funded collaborative involving Universities and DOE National Labs

- Montana State University - Lead Institution
- Los Alamos National Laboratory
- Pacific Northwest National Laboratory
- West Virginia University
- Lawrence Berkeley National Laboratory
- National Energy Technology Laboratory
- Lawrence Livermore National Laboratory

Near – Surface Monitoring Zones

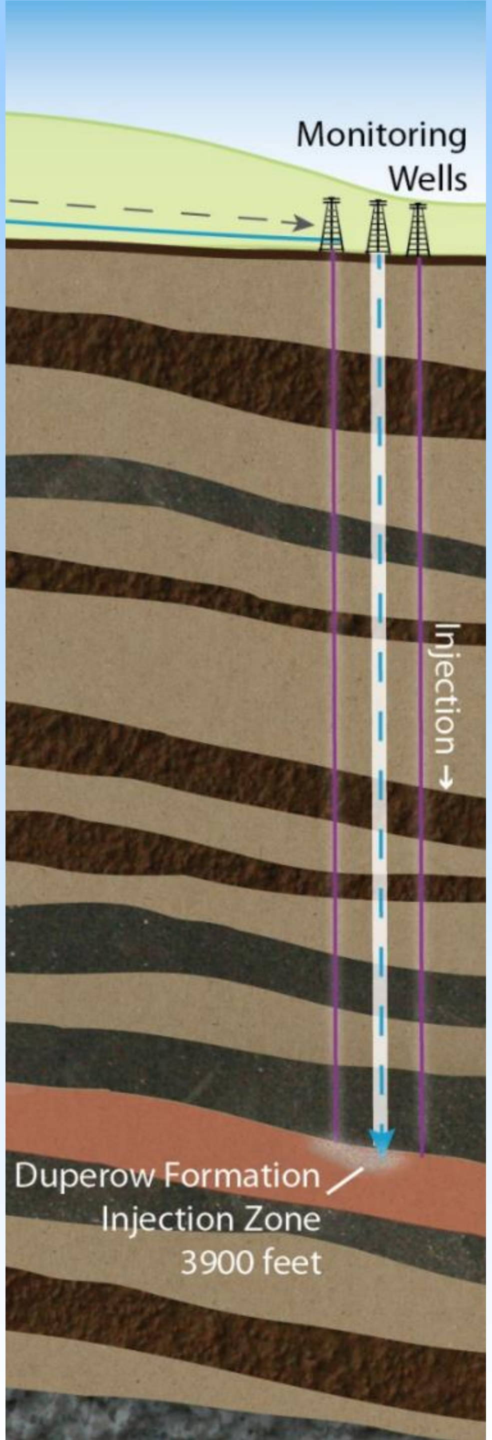
Atmosphere

Biosphere

Soil
(Vadose & Shallow Saturated Zones)

Caprock &
Deep Overburden

Injection Zone



- **Atmosphere**
  - Ultimate Integrator
  - Dynamic
  - Monitoring & Modeling
- **Biosphere**
  - dynamic
  - requires protection
  - opportunity for wide area monitoring but indirect methods
- **Soil**
  - Integrates
  - dynamic
- **Aquifers**
  - Integrates
  - Requires protection

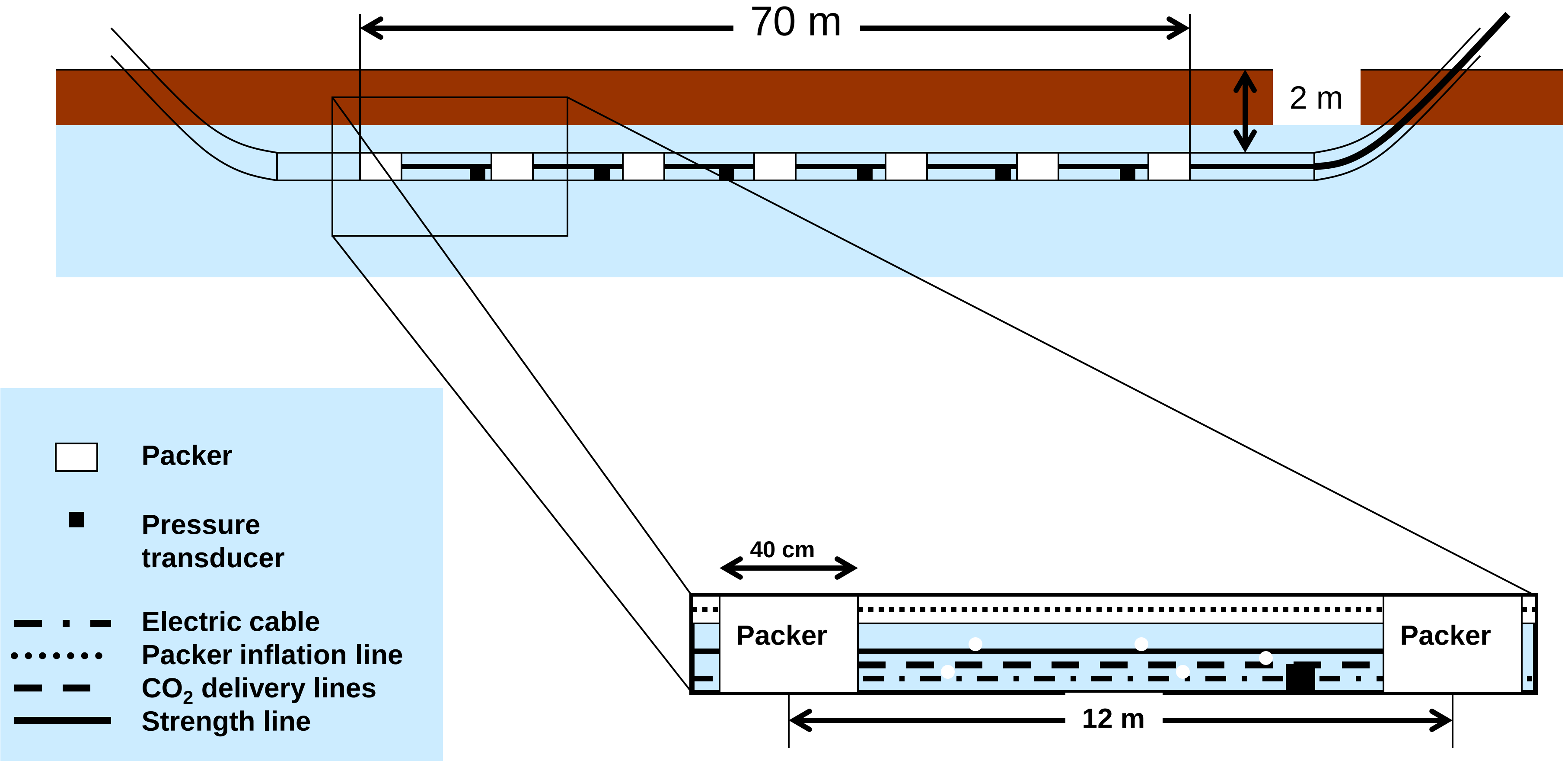
Motivation (2006)

The situation in 2006 when we started planning the work:

- **Near-surface detectors were considered highly desirable for public assurance**
- **They had been deployed at sequestration pilot sites**
- **These pilot sites were well chosen and do not leak**
- **Thus, the near-surface detection techniques had not been adequately tested under realistic conditions**
- **The primary initial purpose was detection verification**

Horizontal Well Installation

Ray Solbau, Sally Benson

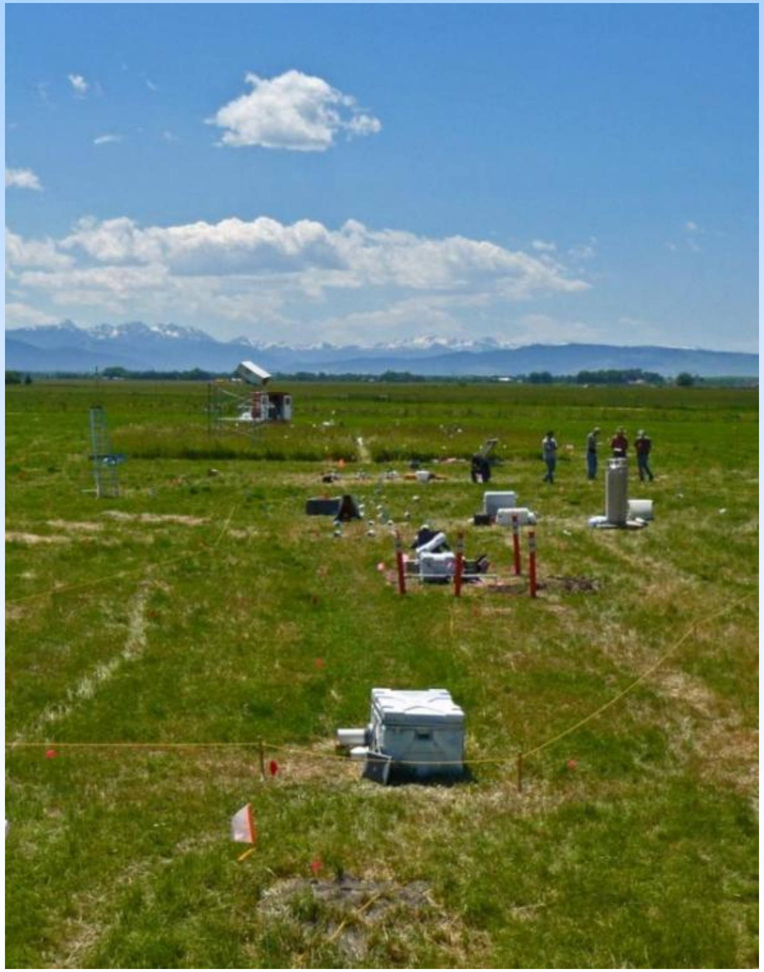


Methods

- Soil Gas Monitoring
- In-situ soil gas probes
- Eddy Covarience
- Soil Flux chambers
- Differential Absorption LIDAR
- Cavity ring-down, other isotopic measurements
- Water chemistry
- Tracers
- Hyperspectral / mutispectral imaging
- Many more

Large Number of Participants / Methods

47 investigators
31 instruments / sensor arrays
5 univ. 6 DOE labs, 4 companies



Investigator	Institution	Monitoring Technology	Number of Sensors
Arthur Wells Rod Diehl Brian Strasizar	National Energy Technology Laboratory	Atmospheric tracer plume measurements	1 tower (4m) Blimp (Apogee Scientific) with 3 tether line samplers
		Bee hive monitoring for tracer with sorption tube and pollen trap	2 hives
		Automated Soil CO_2 flux system	4 chambers
William Pickles Eli Silver Erin Male	University of California- Santa Cruz	Hand held hyperspectral measurements (plant health)	1 instrument
Yousif Kharaka James ThordsenGil AmbatsSarah Beers	United States Geological Survey*	Ground water monitoring	1 EC and temperature probe, Dissolved oxygen probe, lab analysis of water samples
Henry Rauch	West Virginia University	Water monitoring well headspace gas sampling	1 sensor
Lucian Wielopolski Sudeep Mitra	Brookhaven National Laboratory*	Ineleastic neutron scattering (total soil carbon)	1 instrument
Martha Apple Xiaobing Zhou Venkata Lakkaraju Bablu Sharma +2 students	Montana Tech*	Soil moisture, temp. Chlorophyll Content Meter , Fluorescence Meter , LI-COR 2000 to measure leaf area index Leaf Porometer to measure stomatal conductance	5 sensors
		Infrared radiometry (plant health)	2 instruments
		Atmospheric humidity and temperature, accumulated rainfall	1 sensor each
		Plant root imaging	1 camera
		Soil conductivity	1 sensor
		Handheld hyperspectral measurements (plant health)	1 instrument
William Holben Sergio Morales	University of Montana*	Microbial studies	Lab analysis

Zero Emissions Research and Technology

Large Number of Participants / Methods

Investigator	Institution	Monitoring Technology	Number of Sensors
Lee Spangler Laura Dobeck Kadie Gullickson	Montana State University	Water content reflectometers (soil moisture)	15 sensors
		Automated soil CO_2 flux system	5 long term chambers, 1 portable survey chamber
		CO_2 soil gas concentration	6 sensors
Kevin Repasky (PI) Jamie Barr	Montana State University	Underground fiber sensor array (CO_2 soil gas concentration)	4 sensors
Rand Swanson	Resonon*	Flight based hyperspectral imaging system	1instrument
Joseph Shaw (PI) Justin Hogan Nathan Kaufman	Montana State University	Multi-spectral imaging system (plant health)	1instrument
		Meteorological measurements	1 tower
Julianna Fessenden +3 students	Los Alamos National Laboratory	In situ (closed path) stable carbon isotope detection system	1 instrument
		Flask sampling for in situ isotope detection	Lab analysis
Sam Clegg Seth Humphries	Los Alamos National Laboratory	Frequency-modulated spectroscopy (FMS) open-air path	1 instrument
Thom Rahn	Los Alamos National Laboratory	Eddy covariance	1 tower
James Amonette Jon Barr	Pacific Northwest National Laboratory	Soil CO_2 flux (steady-state)	27 chambers
Sally Benson (PI) Sam Krevor Jean-Christophe Perin Ariel Esposito Chris Rella (Picarro)	Stanford University* / Picarro Instruments*	Commercial cavity ringdown real-time measurements of $\delta^{13}C$ and CO_2 in air	1 instrument
Greg Rau Ian McAlexander (LGR)	Lawrence Livermore National Laboratory /Los Gatos Research*	Commercial cavity ringdown real-time measurements of $\delta^{13}C$ and CO_2 in air	1 instrument
Jennifer Lewicki	Lawrence Berkeley National Laboratory	CO_2 soil gas concentration	8 sensors
		CO_2 atmospheric concentration	2 sensors
		Chamber soil CO_2 flux measurements	1 instrument
		Meteorological	1 tower

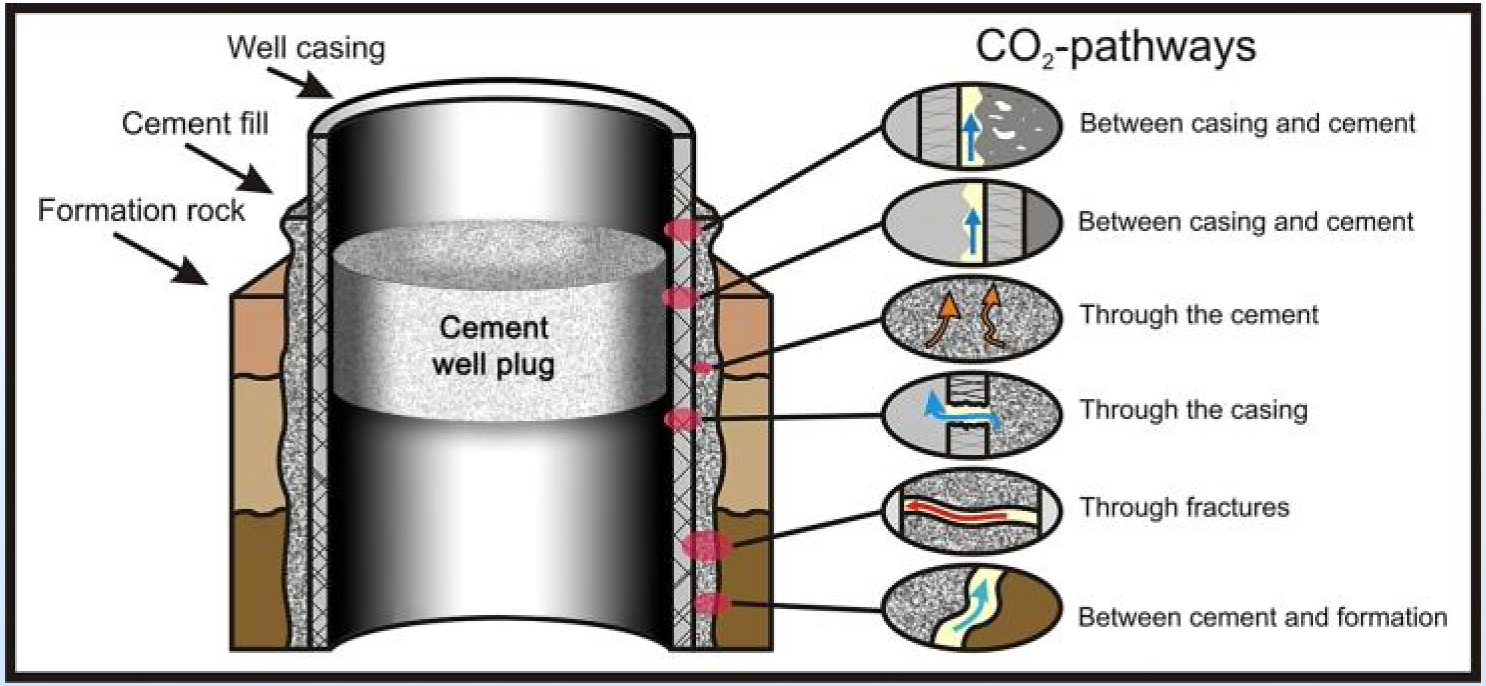
Well Bore Leakage Mitigation using Engineered Biomineralization

Al Cunningham
Lee Spangler, Robin Gerlach, Adie Phillips
Montana State University

Funding from USDOE ZERT, FE0004478, FE0009599
Collaborators Shell, SC, Stuttgart, SLB, UAB

Project Concept

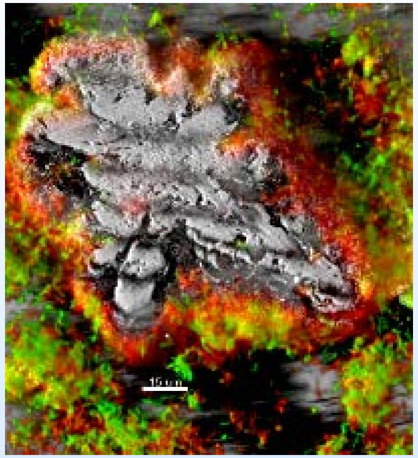
-MICP sealing with low-viscosity fluids-



After Nordbotten and Celia, Geological Storage of CO_2, 2012

- **Cement is a good technology for large aperture leaks, but is too viscous to plug <u>small aperture leaks</u> (small <u>fractures</u> or <u>interfacial delaminations</u>).**
- **In some cases it is also desirable to plug the <u>rock formation near the well</u>.**
- **A missing tool is a plugging technology that can be delivered via <u>low-viscosity</u> fluids**

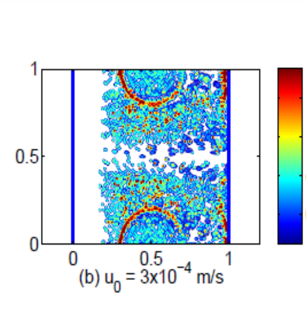
Calcite Biomineralization (MICP) Using Ureolytic Bacteria

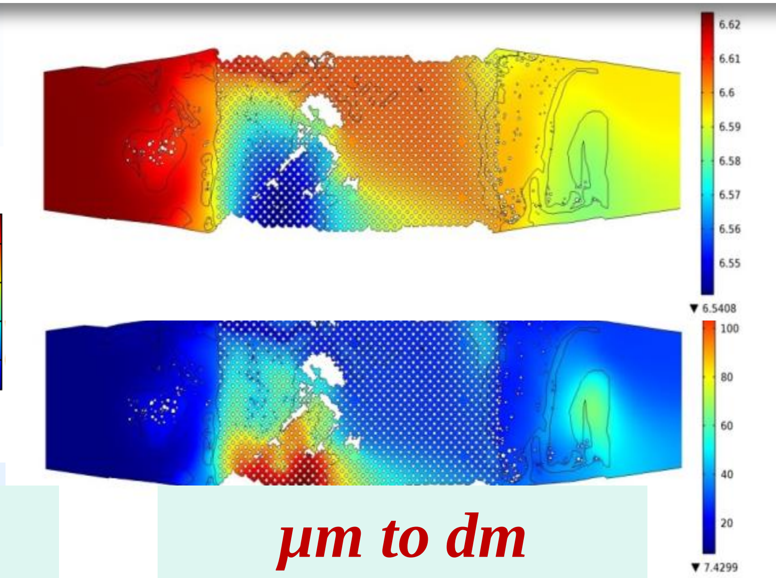


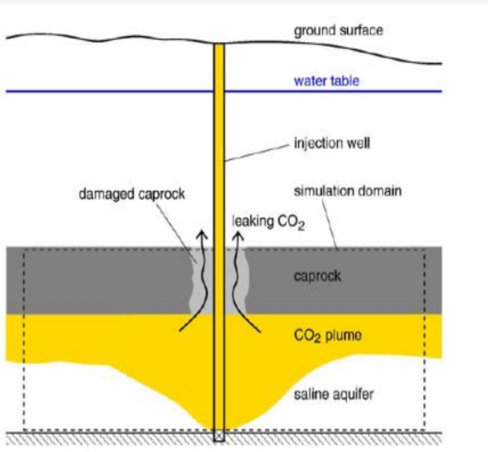
L.Schultz/B.Pitts

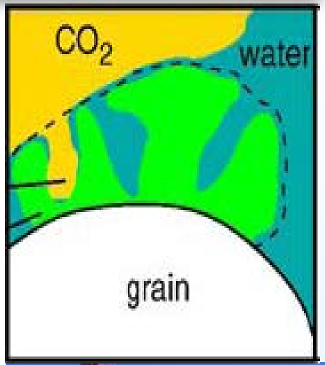
- $NH_2CONH_2 + H^+ + H_2O \leftrightarrow 2NH_4 + HCO_3^-$ (1)
- $Ca^{+2} + 2HCO_3^- \leftrightarrow CaCO_3(s) + CO_2 + H_2O$ (2)
- The enzyme urease present in some bacteria (i.e. (*Sporosarcina pasteurii*) hydrolyzes urea to form ammonium which increases pH
- HCO_3^- is subsequently produced which in the presence of Ca^{+2} precipitates calcium carbonate (Calcite)

Scales of Experimentation and Modeling





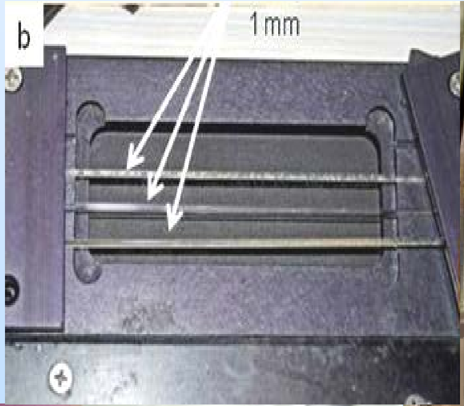




nm to cm

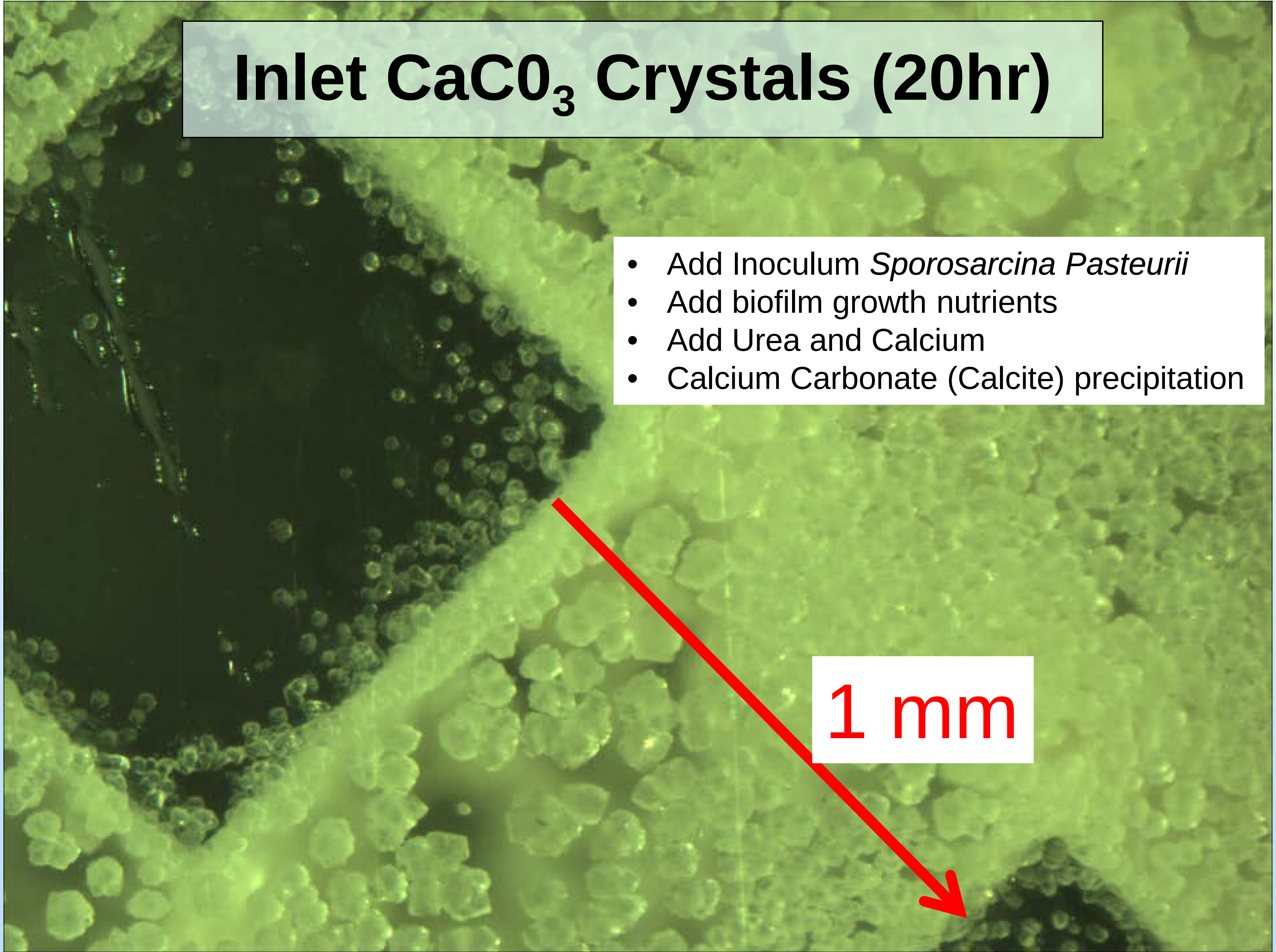
µm to dm

cm to 100s of m

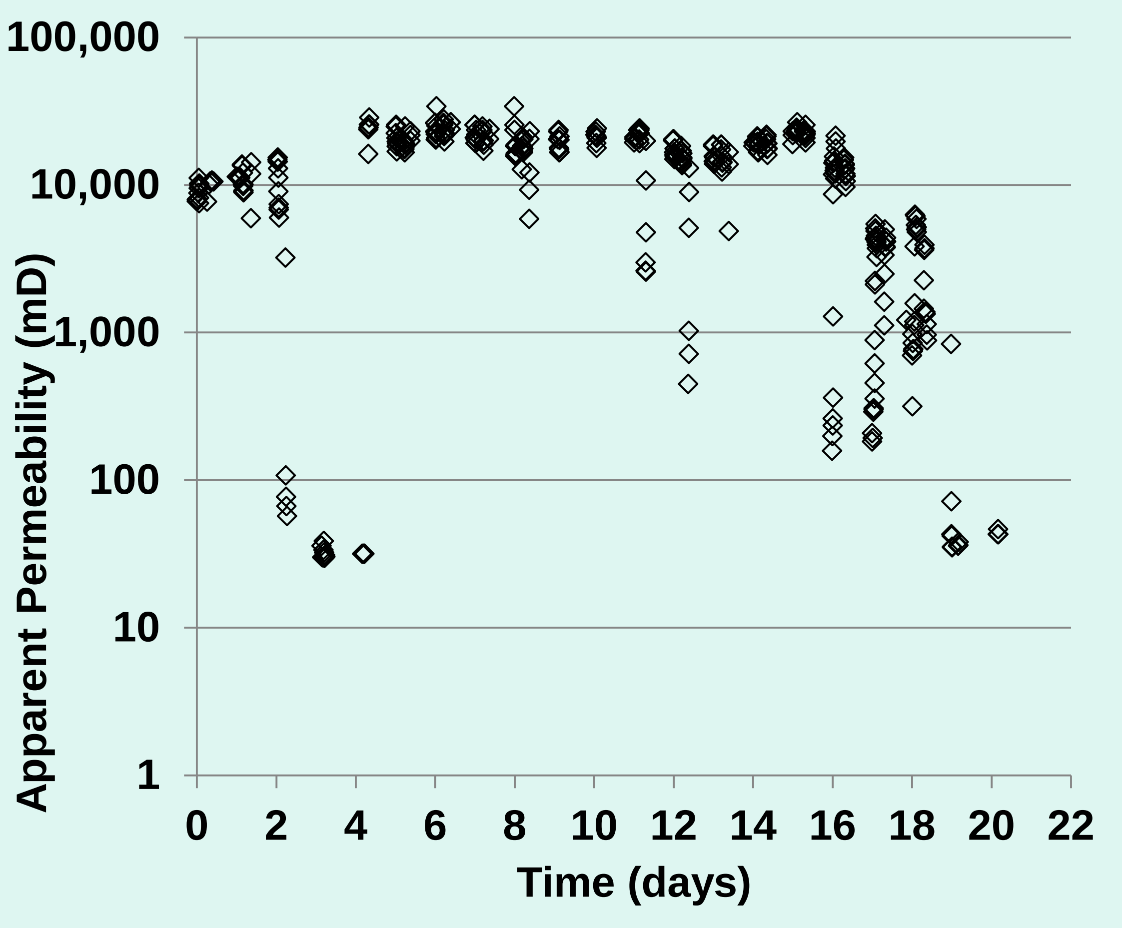


Inlet $CaC0_3$ Crystals (20hr)

- Add Inoculum *Sporosarcina Pasteurii*
- Add biofilm growth nutrients
- Add Urea and Calcium
- Calcium Carbonate (Calcite) precipitation

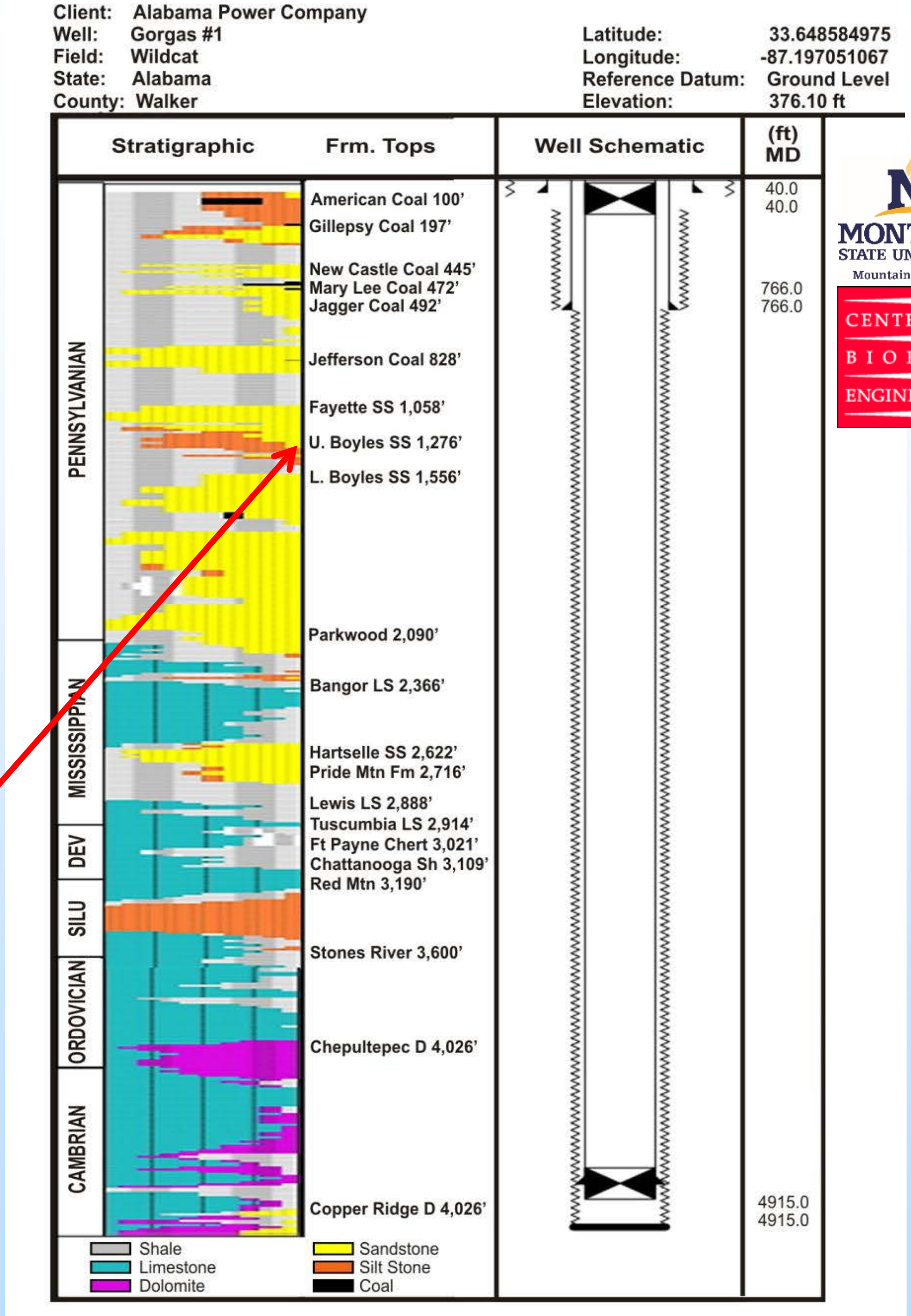


Fracture Sealing at 45 bar



Phillips, AJ, Eldring, J, Hiebert, R, Lauchnor, E, Mitchell, AC, Gerlach, R, Cunningham, A, and Spangler, L. High pressure test vessel for the examination of biogeochemical processes. In preparation for J. Petrol. Sci. Eng.

Gorgas well and Test site



MONTANA STATE UNIVERSITY
Mountains & Minds
CENTER FOR BIOFILM ENGINEERING

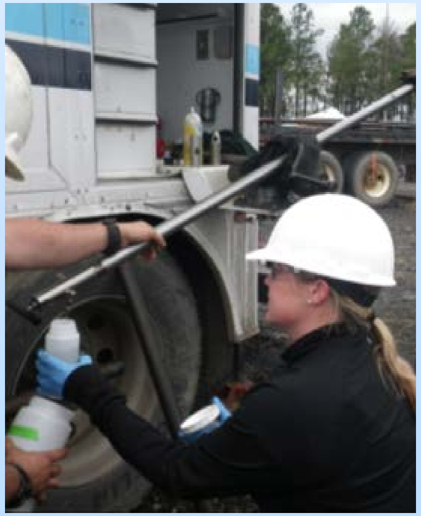
Total well depth 4915 ft
Test was conducted at 1118 ft, bgs

Field Deployment- Fracture Sealing

- Bailer delivery system
- Injection strategy
- Mobile laboratory- microbe cultivation
- Sampling

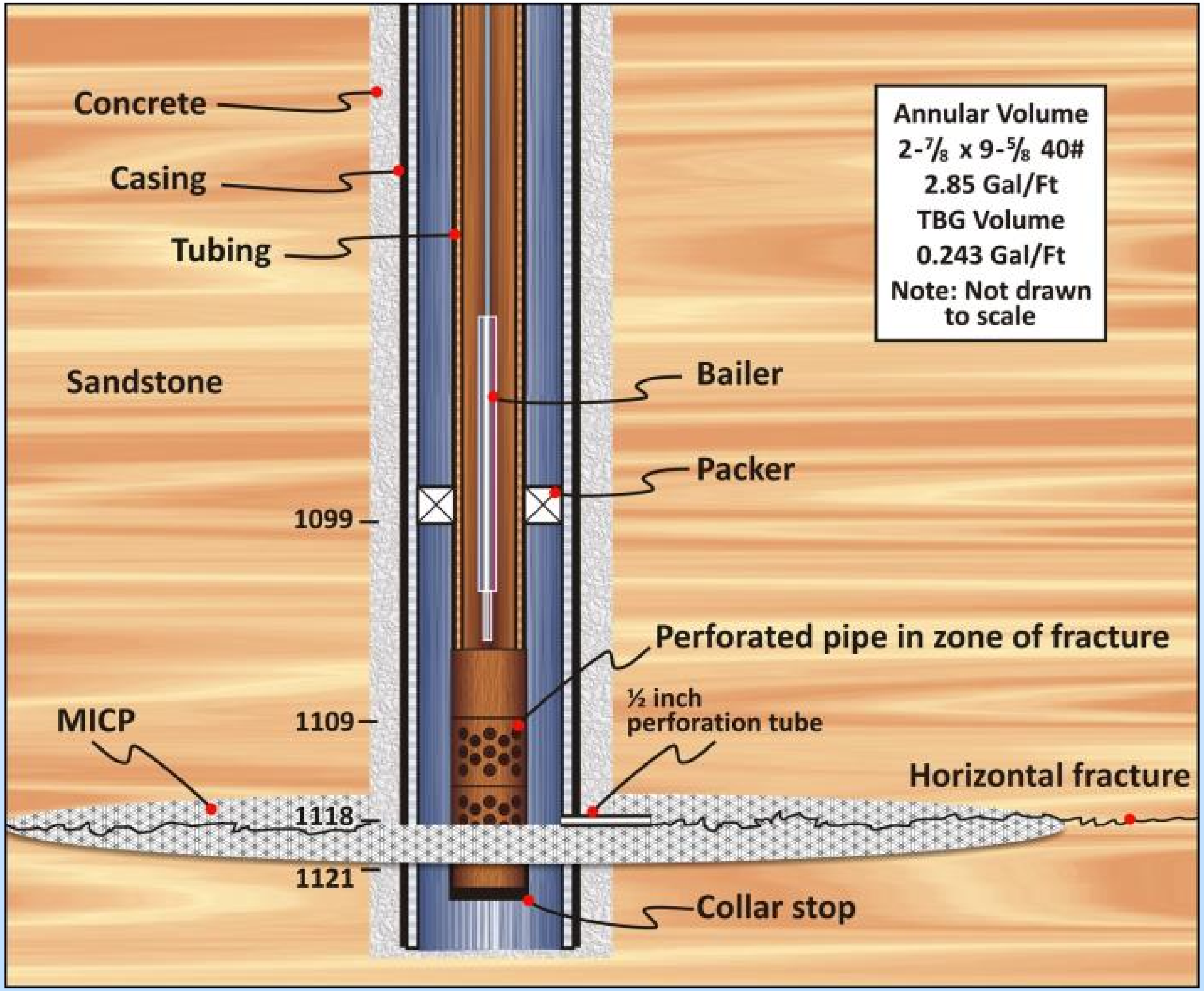
SOUTHERN COMPANY

Schlumberger



<u>Complete sealing</u> after 3 days:

24 calcium injections, 6 inoculation injections, 15 kg Ca



Tan colonies

S. Pasteurii

MICP model simulation using Gorgas field protocol made prior to field injection

Volume fraction of calcite (0.125 m³ $CaCO_3$/m³) at the end of the MICP simulation.

25 Ca injections, 6 Inoculation injections, 11kg of Ca total,