Big Sky Regional Carbon Sequestration Partnership – Kevin Dome Carbon Storage

FC26-05NT42587

Lee Spangler, Montana State University

Dave Bowen, Vecta Oil and Gas

Wayne Rowe, Schluberger Carbon Services

Big Sky Carbon Sequestration Partnership

U.S. Department of Energy

National Energy Technology Laboratory

Strategic Center for Coal's

FY14 Regional Carbon Sequestration Partnerships Expert Review

August 2014

Project Team Members

Universities	Private Companies	National Laboratories
Montana State University	Vecta Oil and Gas	Los Alamos National Laboratory
Washington State University	Altamont	Lawrence Berkeley National Laboratory
Columbia University	Schlumberger Carbon Services	Idaho National Laboratory
Barnard College		

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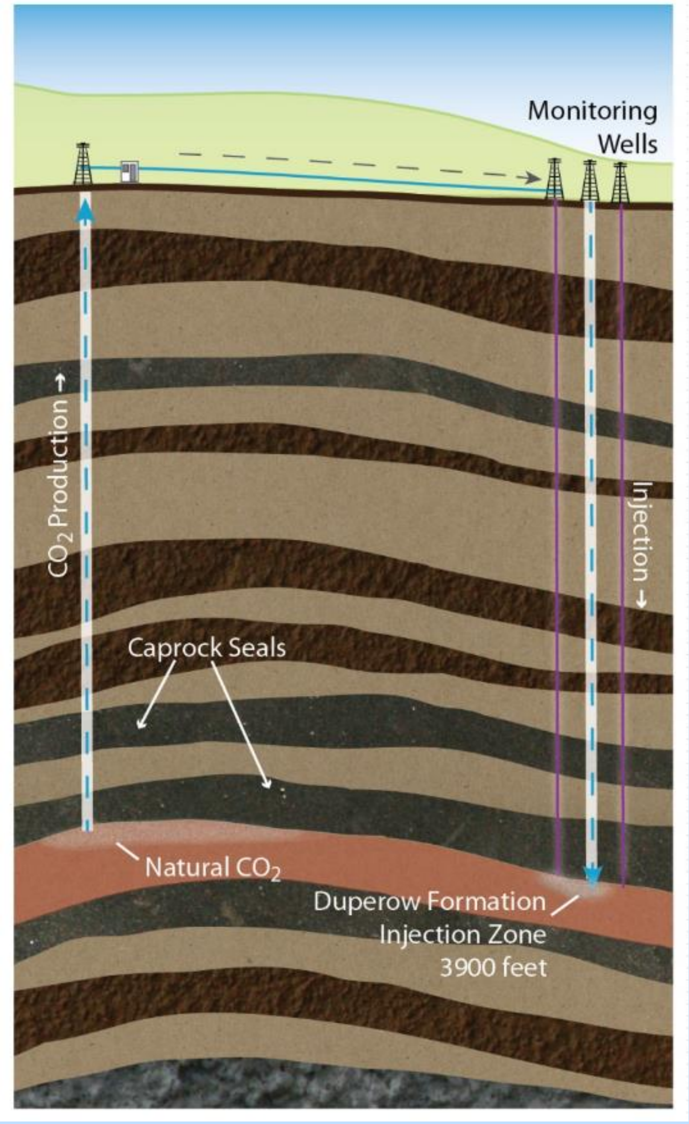
Presentation Outline

- Program Goals / Scope of Work / Goals & Objectives
- Project Overview
  - Geology of Kevin Dome / Regional Significance
  - Site Characteristics – Scientific Opportunities
- Site Characterization
- Monitoring
- Modeling
- Results to Date and Accomplishments
- Summary

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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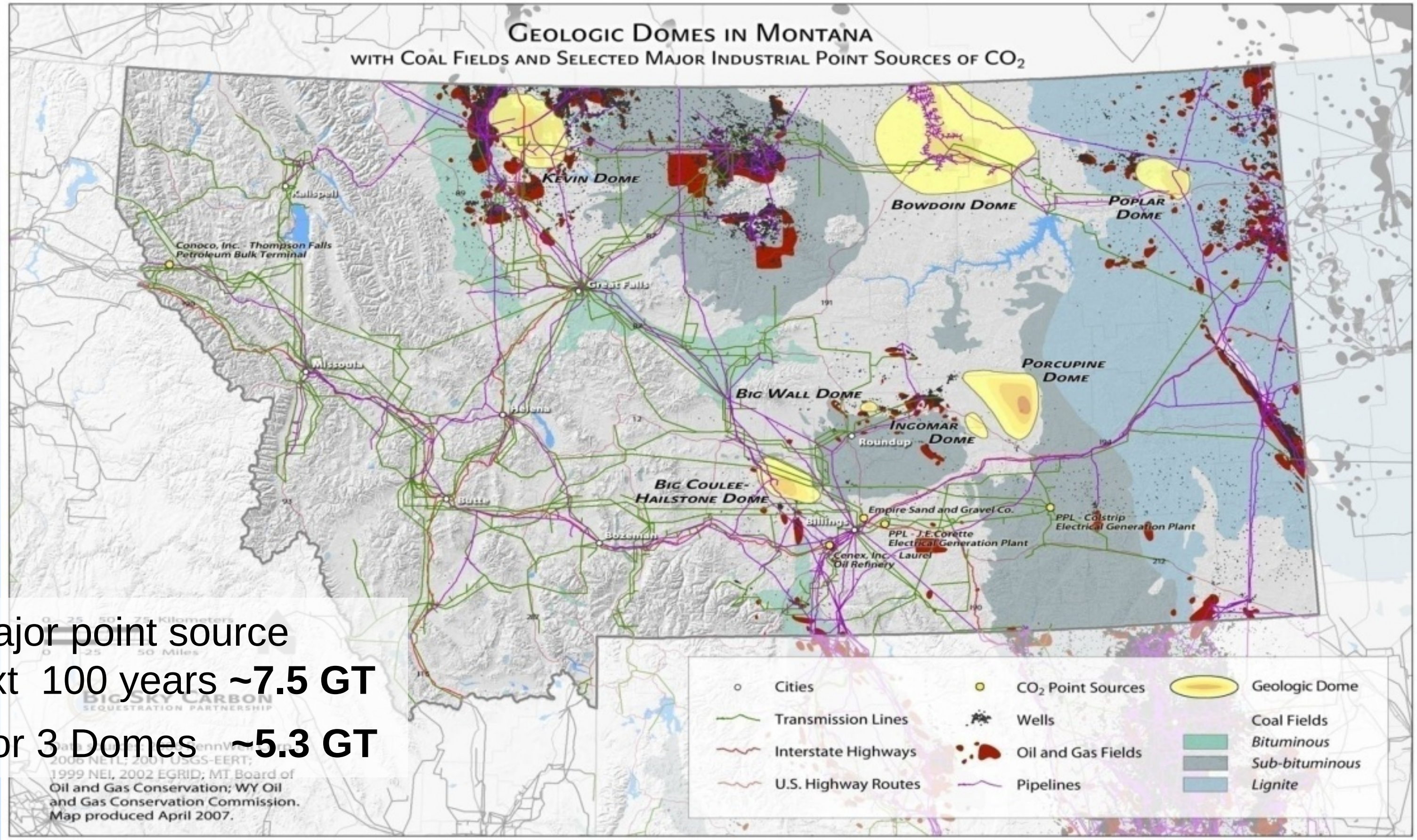
Domes Are Attractive Early Storage Target



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

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

- Prevent trespass issues – buoyancy flow will take CO_2 to top of dome
- Potential use as carbon warehouse – decouple anthropogenic CO_2 rate from utilization rate

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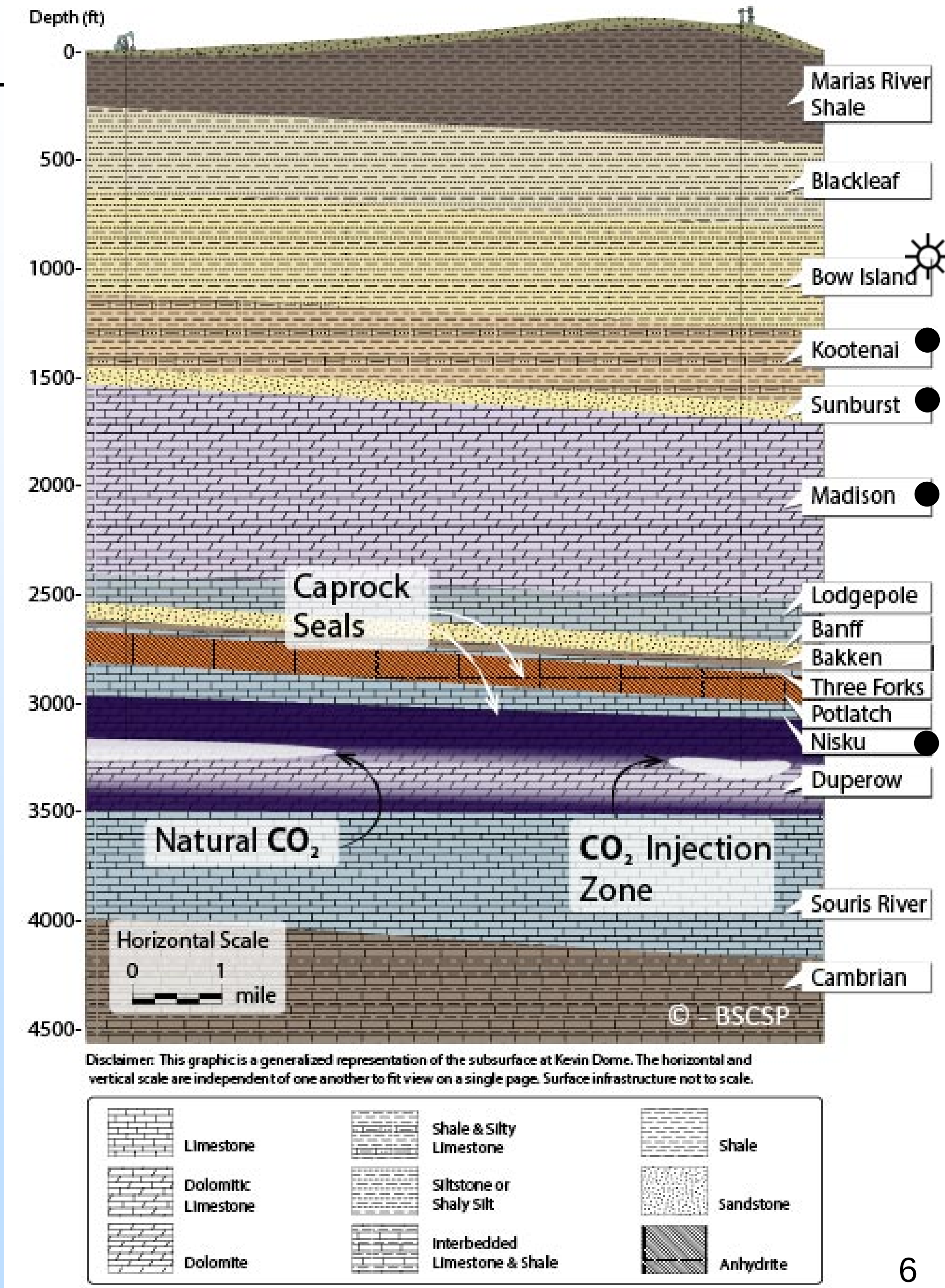
Kevin Dome

CO_2 in middle Duperow

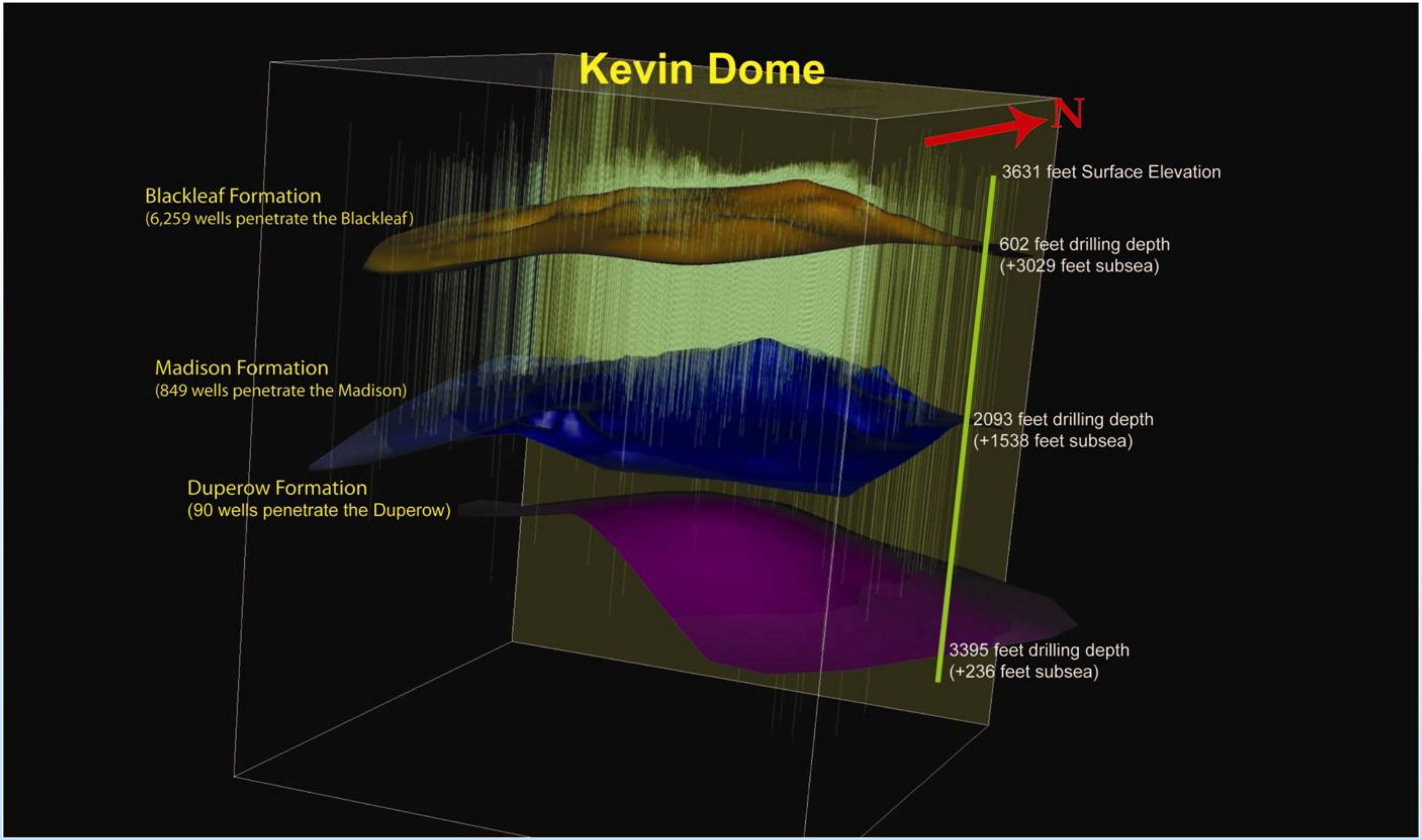
Two “gold standard” seals

- Upper Duperow ~200’ tight carbonates and interbedded anhydites
- Caprock~ 150’ Anhydrite

Multiple tertiary seals



Kevin Structure Tops & Well Penetrations



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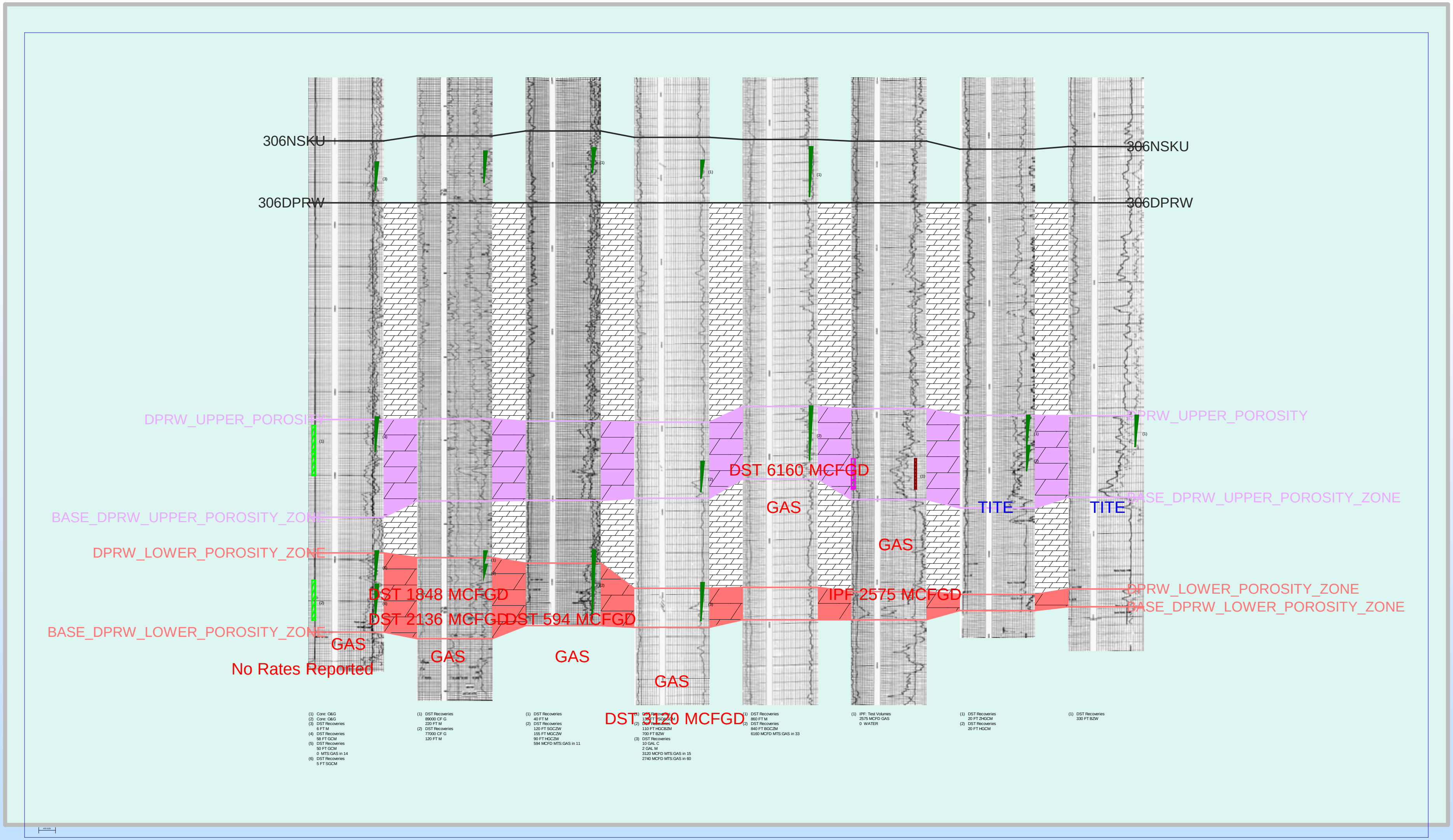
NW - SE Cross Section Kevin Dome



PETRA 11/4/2009 4:13:39 PM (Duperow_XS_11_4.CSP)

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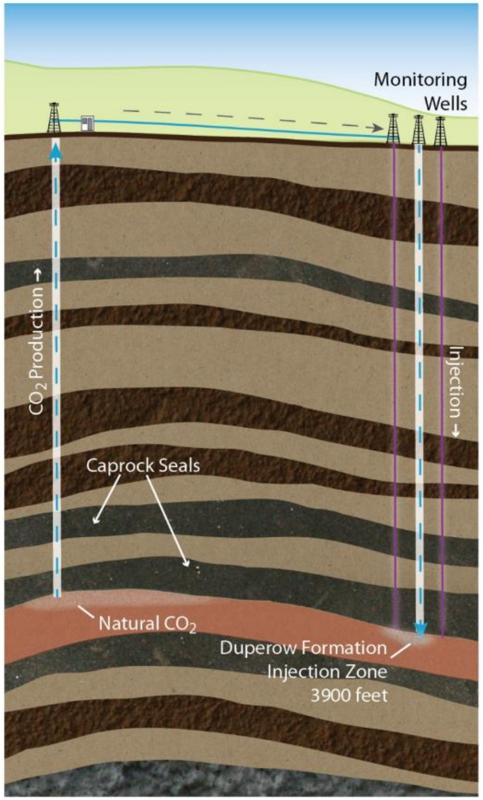
Site Characteristics – Scientific Opportunities



Drilling our own producing wells

- Opportunity to study the natural accumulation and long term effects
- Turns CO_2 procurement cost into scientific opportunity

CO_2 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.

Duperow has two porosity zones

- Opportunity to perform stacked storage or detection limit test depending on the fluid fill in second porosity zone

Site Characterization Approach / Accomplishments

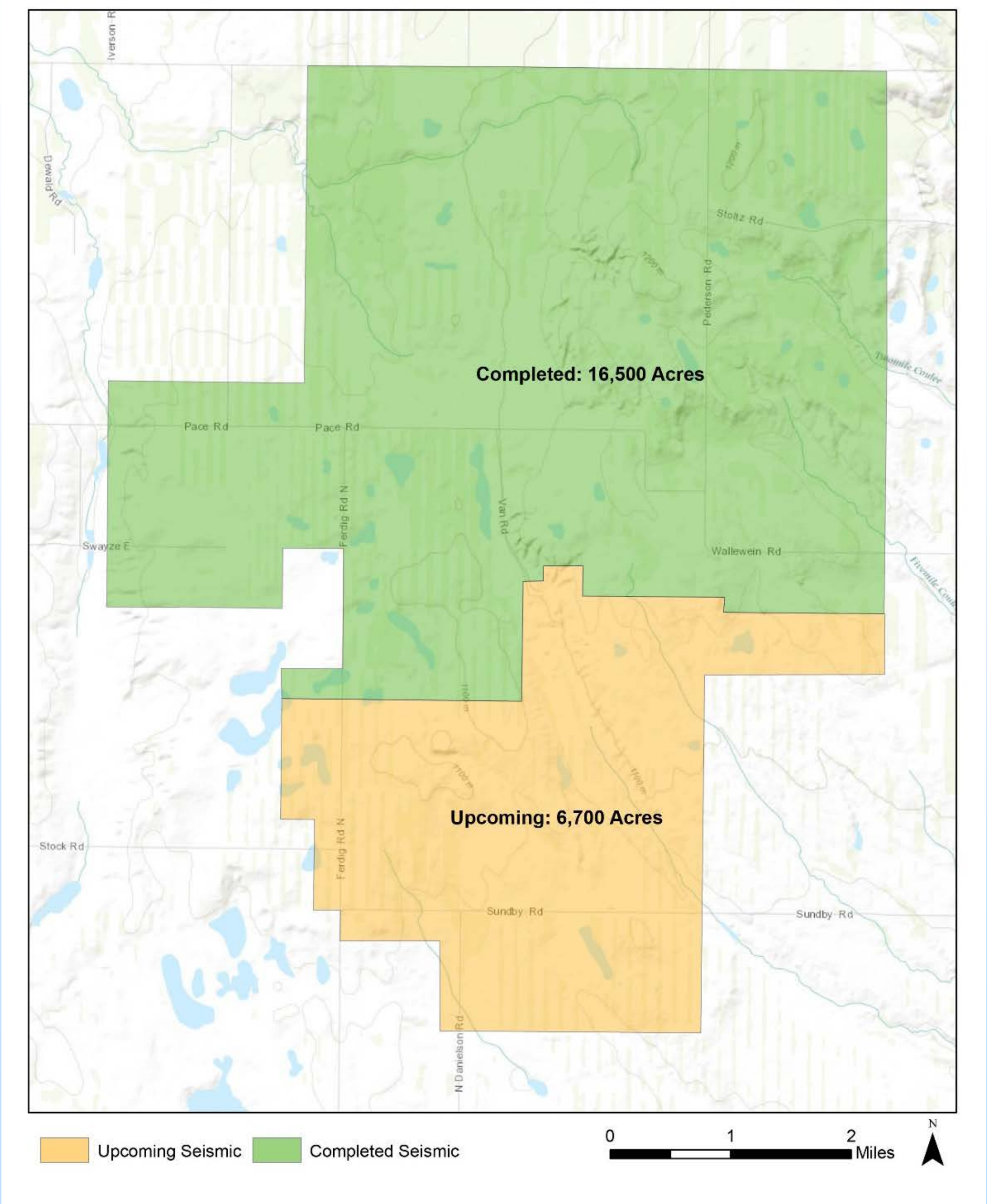
Approach

- Assimilate surface data
  - Topography, water features, viewsheds, infrastructure, cultural resources, biological resources, etc.
- Create GIS products for surface features
- Perform baseline monitoring
- Assimilate subsurface data
  - Wells, tops, logs, 2D seismic, produced water, drilling records
- Create database
- Create static model
- Shoot 3D, 9C seismic
- Drill, Log and Core 1 prod well, 1 inj. region well
  - Perform well tests and core analysis

Key Accomplishments

- Kevin Atlas created with surface and subsurface data incorporated
- ~ 9 sq. mi. 3D, 9C seismic shot, processed and interpreted
- 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
- Core plan developed
- Wells designed
- Cores and Logs acquired
  - Analysis being performed

Seismic



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Modeling

Static Geologic Model

- Three domain sizes (Regional, Dome, Production / Injection)

Multiphase Flow Modeling For CO_2 Injection

- Sensitivity Analysis
  - Three rock parameters (different k, Φ)
  - Two injection rates (constant, stepped)

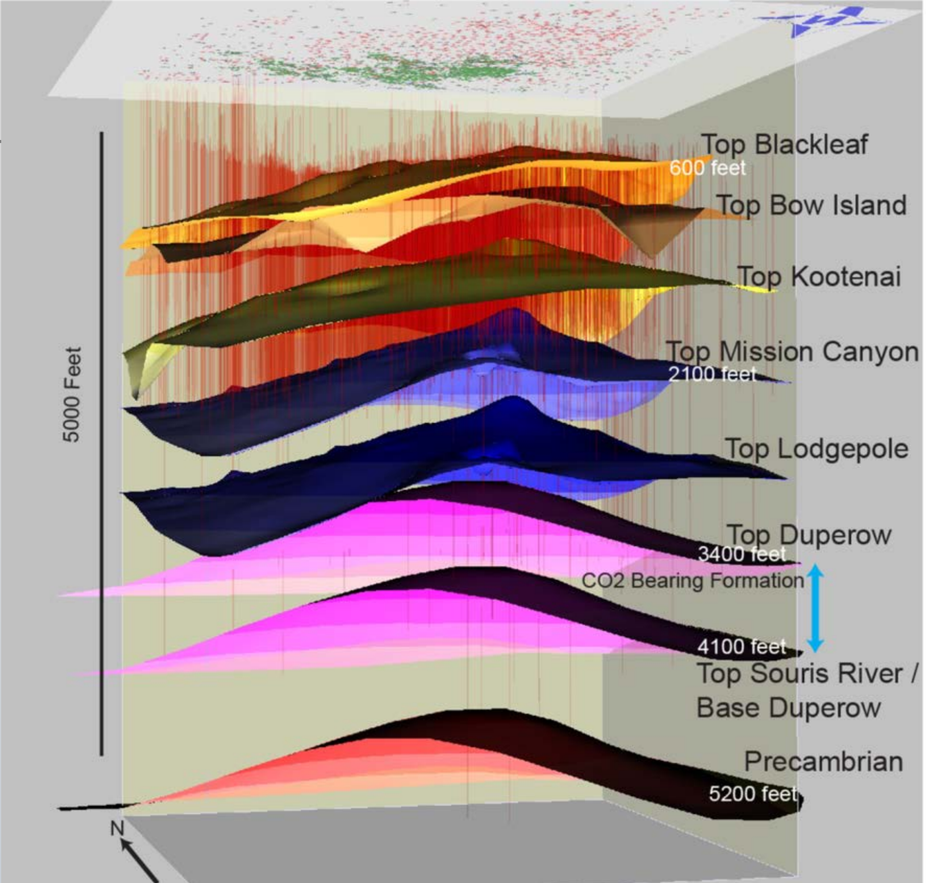
Multiphase Flow – Production

- Sensitivity Analysis
  - Three Gas-water contact heights
  - Pressure effects at multiple distances as a function of production rate / duration

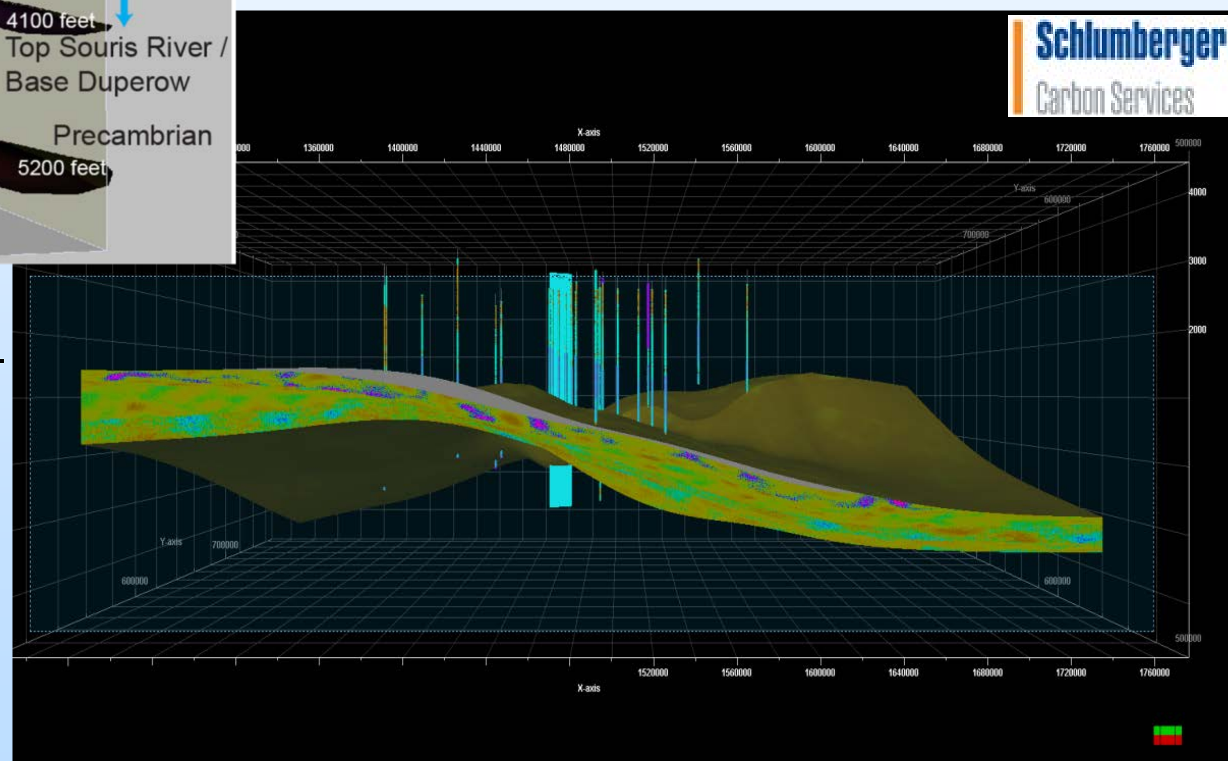
Geochemical & Reactive Transport Modeling

Risk Modeling

Static Model



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

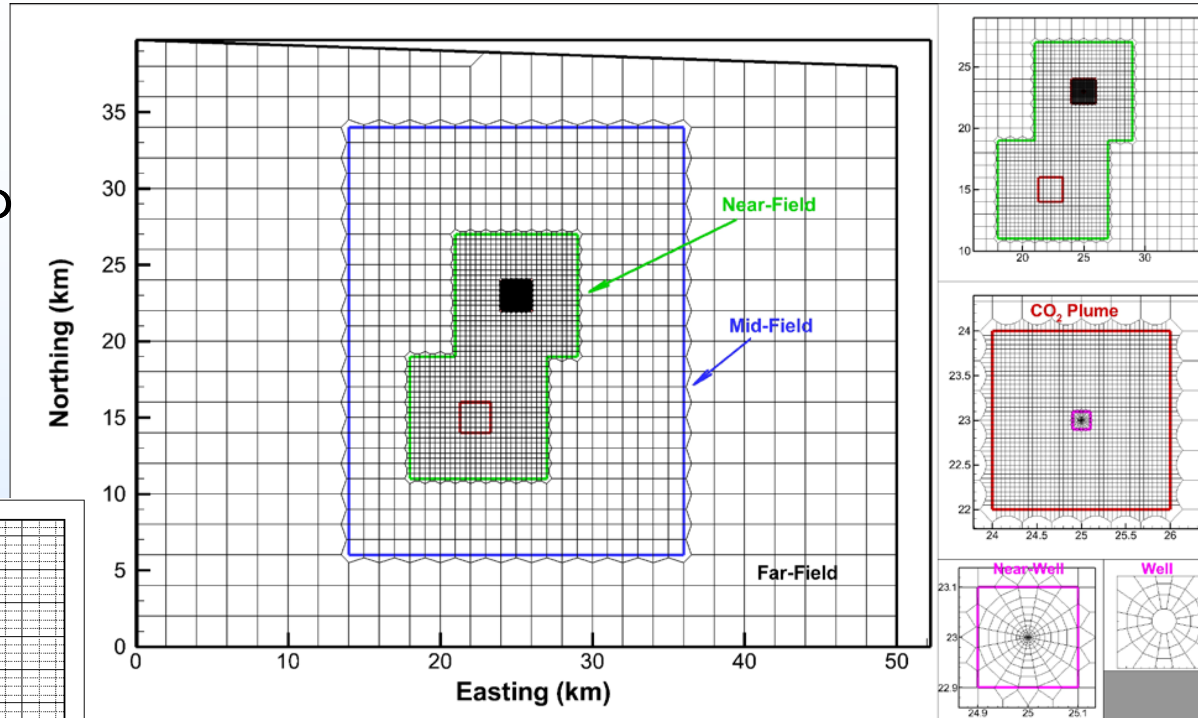


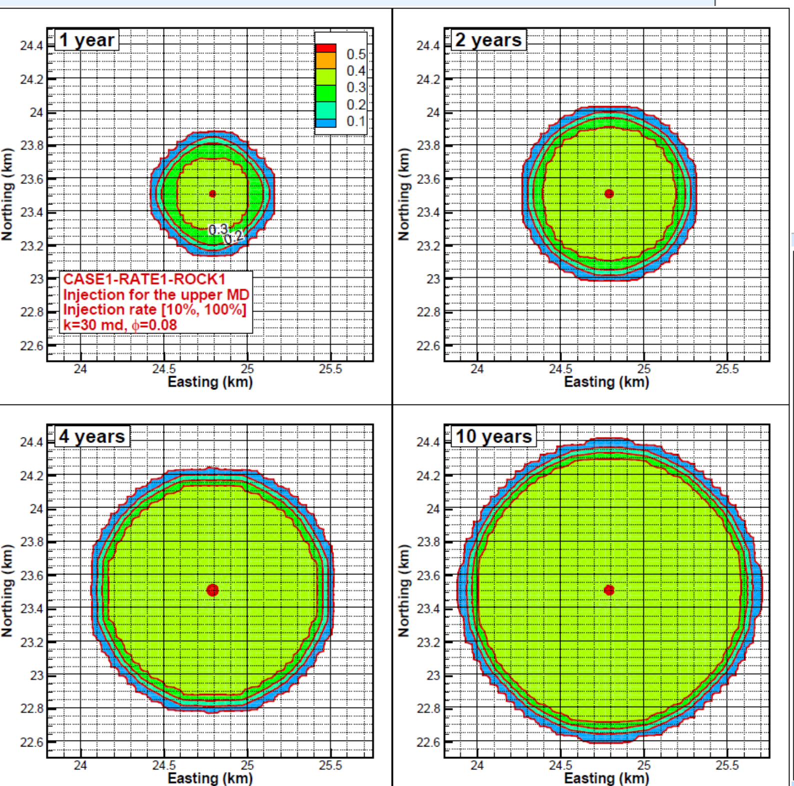
Petrel – Incorporate logs, petro-physical properties (18 wells in injection zone), existing 2D seismic and BSCSP acquired 3D seismic. Export cellular model info for flow modeling.

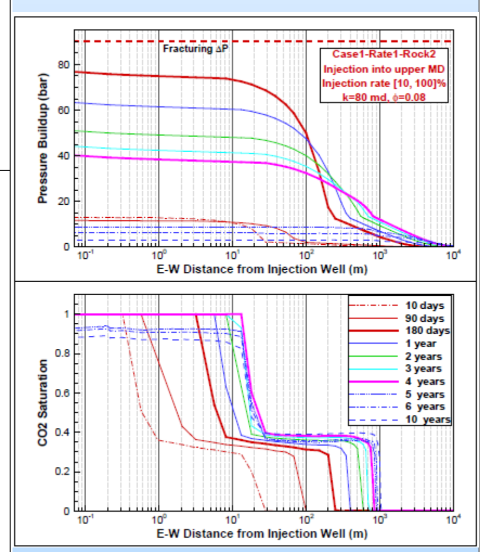
Multi-Phase Flow Modeling-Injection

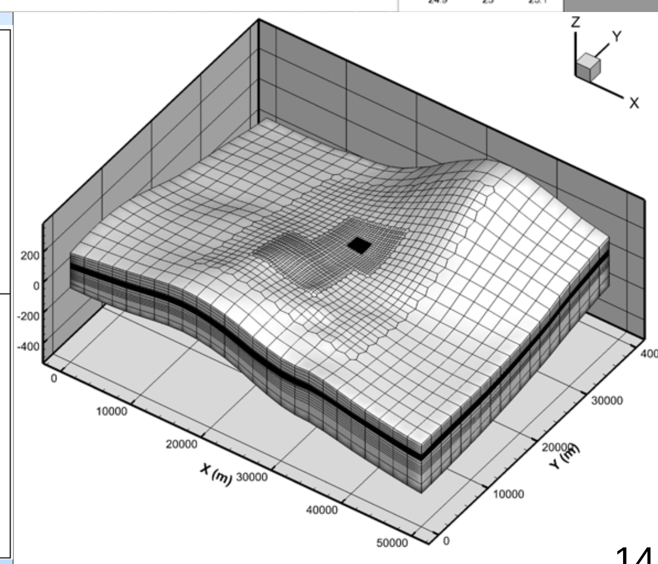
TOUGH2-MP with ECO2N

- Three combinations of k, Φ
- Two injection scenarios
- Investigate pressure, CO_2 saturation

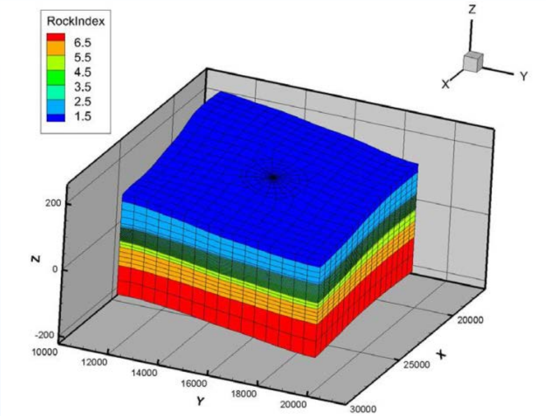






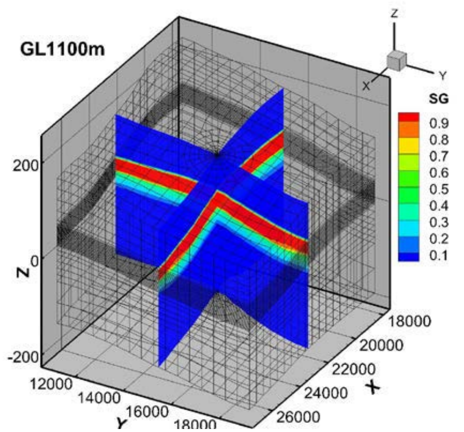


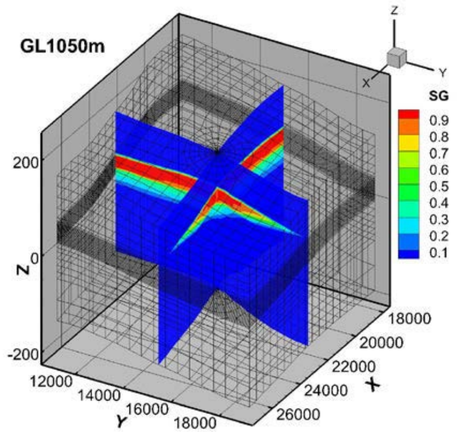
Multi-Phase Flow Modeling-Production

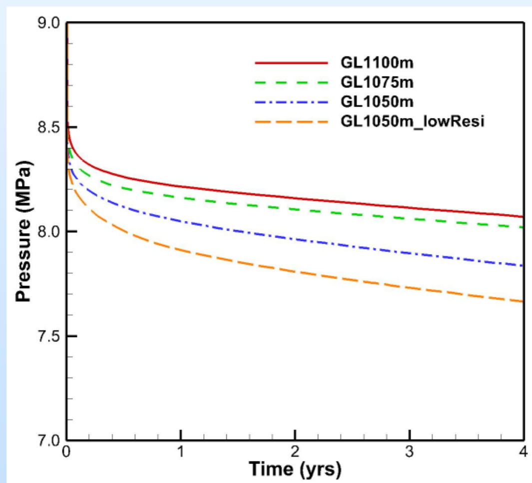


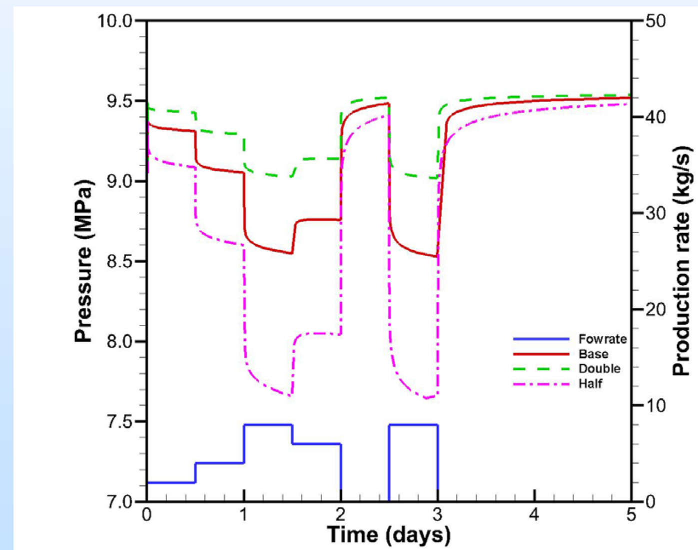
T2Well/ECO2H code - fully coupled wellbore-reservoir flow processes under non-isothermal, two phase (CO_2 and brine) conditions

- Three Gas-water contact heights
- Pressure effects at multiple distances as a function of production rate / duration
- Use to analyze flow test results



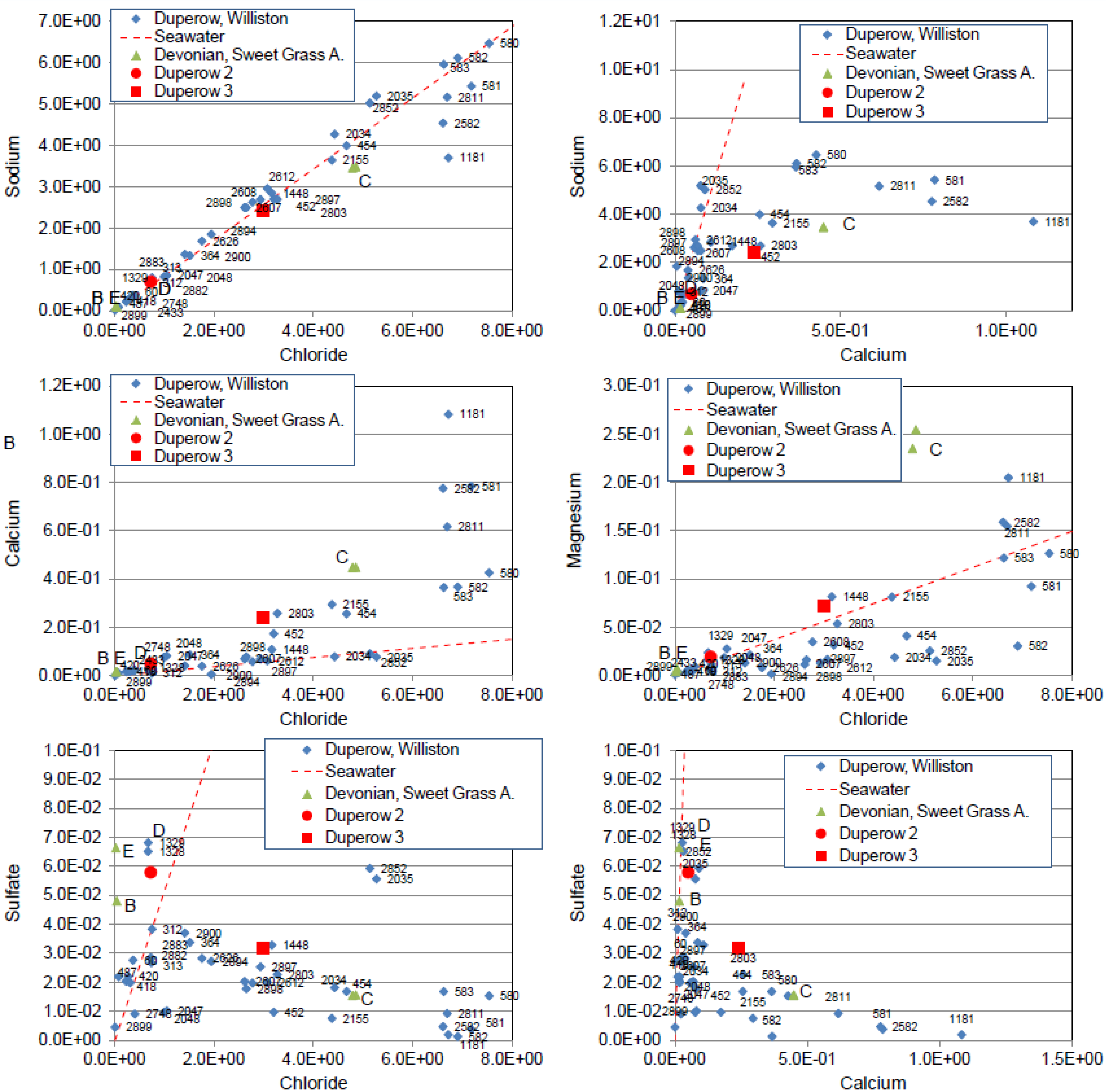






Effect of the reservoir permeability on the down hole pressure as response to the production rate (blue line). Permeability of base case is 3×10-14 m2. “Double” and “half” is w.r.t permeability.

Reactive Transport Modeling



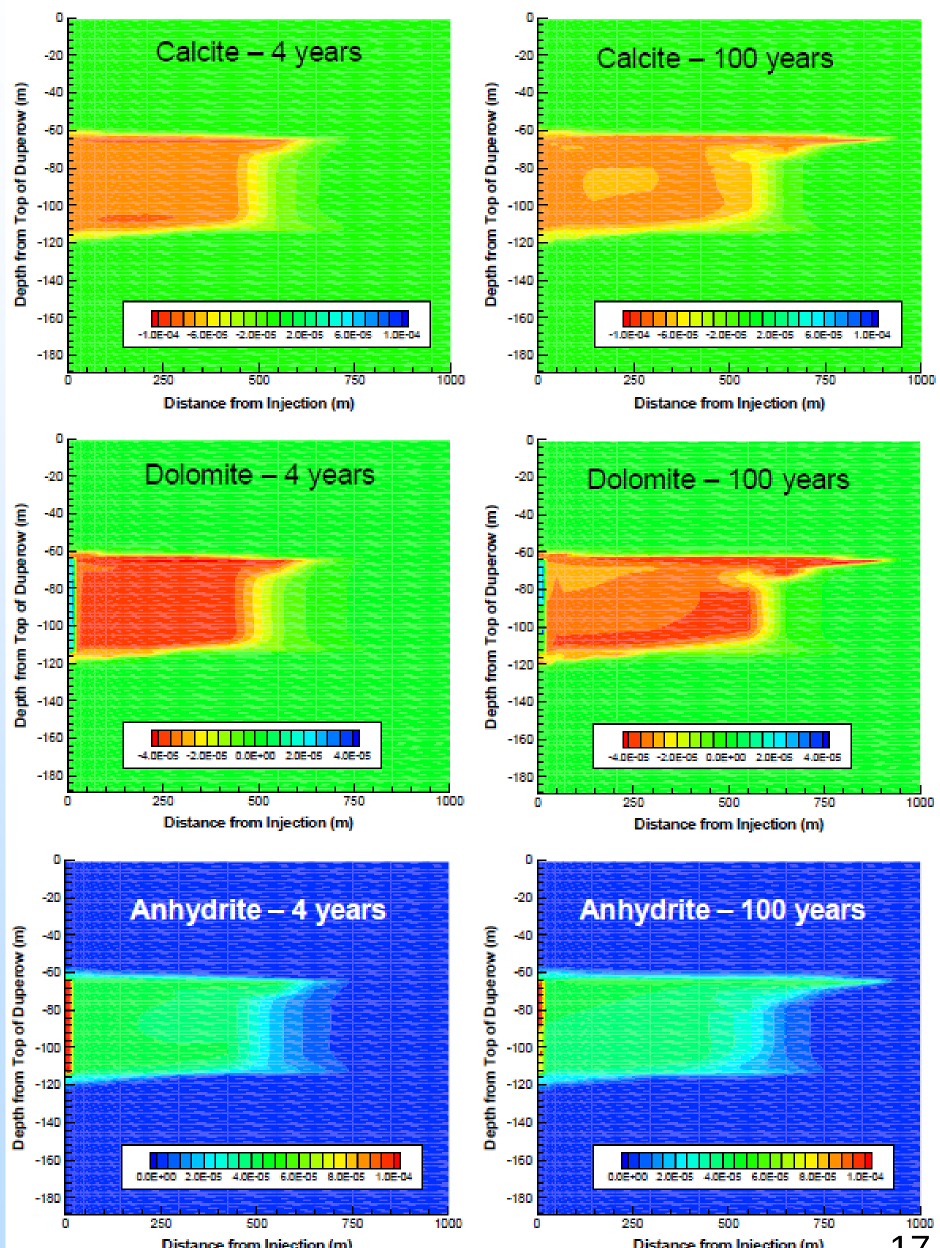
Comparison of data from the USGS produced waters database in Montana (for samples from locations as labeled in the legend). Points Duperow 2 and Duperow 3 are reconstructed compositions, with Duperow 2 used for modeling analyses in this report (Section 5.2). The dashed line represents the seawater evaporation/dilution trend.

Reactive Transport Modeling
(cont.)

BERKELEY LAB

TOUGHREACT
- Calculate CO_2 saturation, pH
- Phases: calcite, dolomite, anhydrite, K-feldspar, illite/mica, siderite, magnesite, and dawsonite

TOUGHREACT simulation of CO_2 injection (1 Mt total) for a period of 4 years into the Middle Duperow formation: predicted amounts of dissolution and precipitation of the most reactive minerals (in volume fraction change from initial conditions; negative for dissolution, positive for precipitation) at the end of the injection period and after a period of 100 years.



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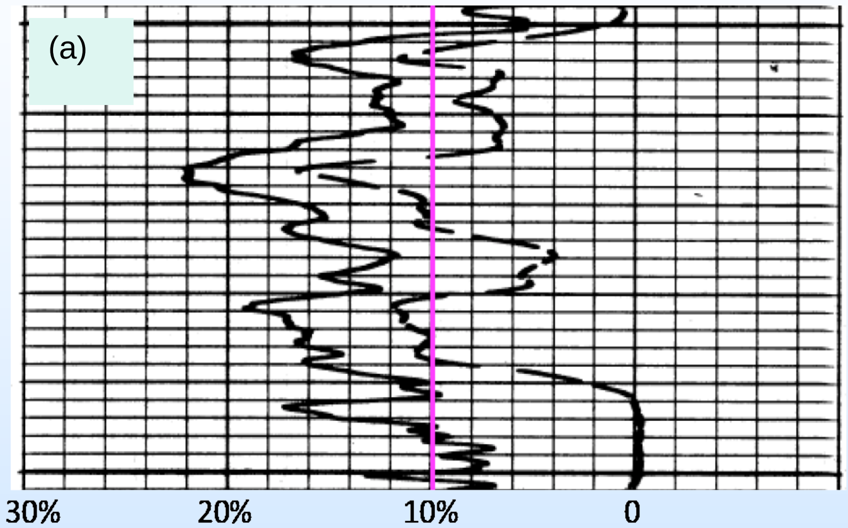
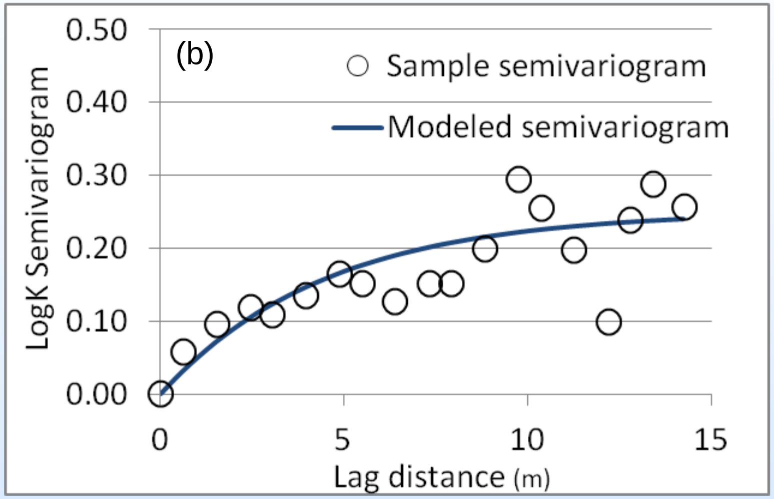
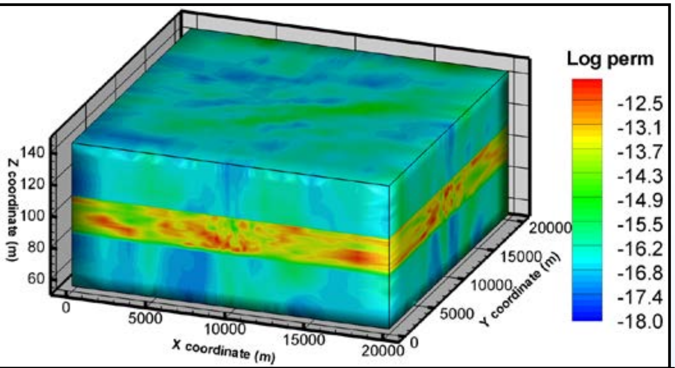
Characterization of multi-scale heterogeneity

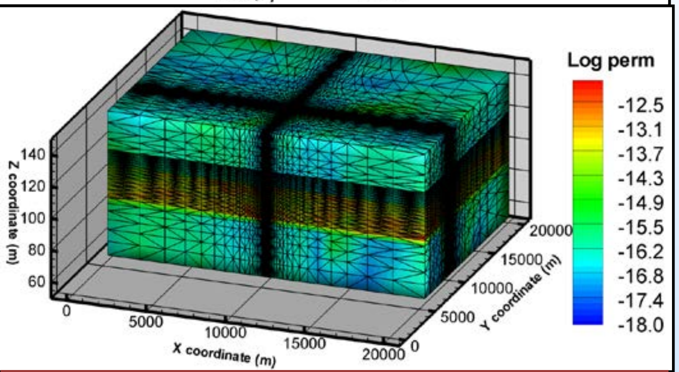




Performed before characterization wells drilled. Consequently, we used data from a well located within 15 km of the site to define the porosity and permeability distributions.

Probabilistic Risk Assessment (Preliminary)

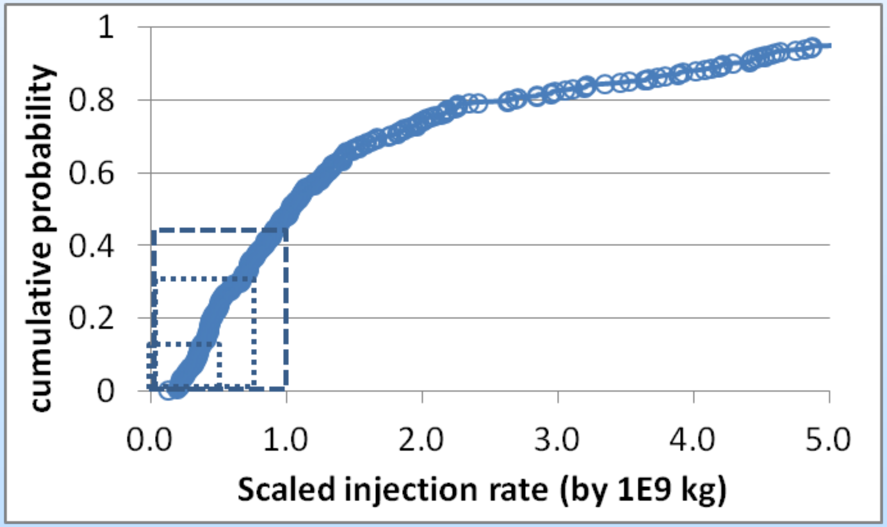




Parameter		Min.	Max.
Reservoir (middle Duperow)	Permeability variance(rVar)	0.1	0.5
	Perm scale (Scale, λ, km)	0.5	5.0
	Anisotropy factor (rFkxz)	1.0	50
	Permeability (rKmean, log m^2)	-15.6	-11.6
	Porosity(rPor)	5%	25%
Caprock	Porosity (cPor)	0.01	0.12
	permeability (cKmean,log m^2)	-18.6	-14.6
	Permeability variance (cVar)		
Injection	Scaled CO_2 injection rate	0	1.0

Heterogeneous reservoir (Middle Duperow) and caprock with mean permeability of -13.5 and -16.2 (logm2), respectively.

Output	Variable name
CO_2 plume size	In x direction
	In x direction
	In x direction
	Radio of Aor
	Area of review
Scaled (by	Injection for 4yrs
10^9kg) injection and	Leakage to caprock
	Leakage to bedrock
leakage rates	Leakage to Madison

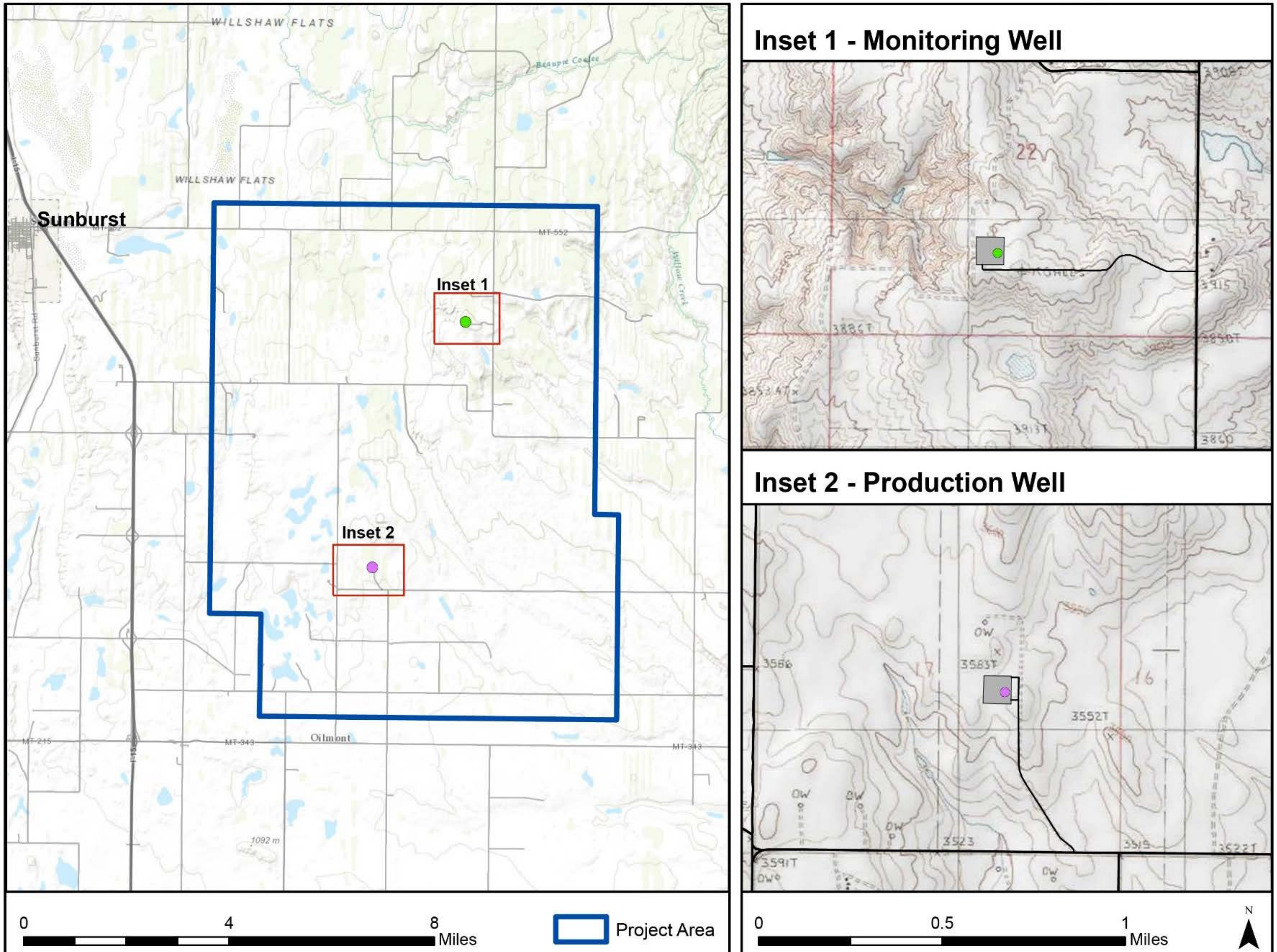


Computed CO2 injection rate distributions (scaled by 1E9 kg) at 4 years from 300 Monte Carlo simulations.

Recap - Saline Storage – Existing Data and Uncertainty

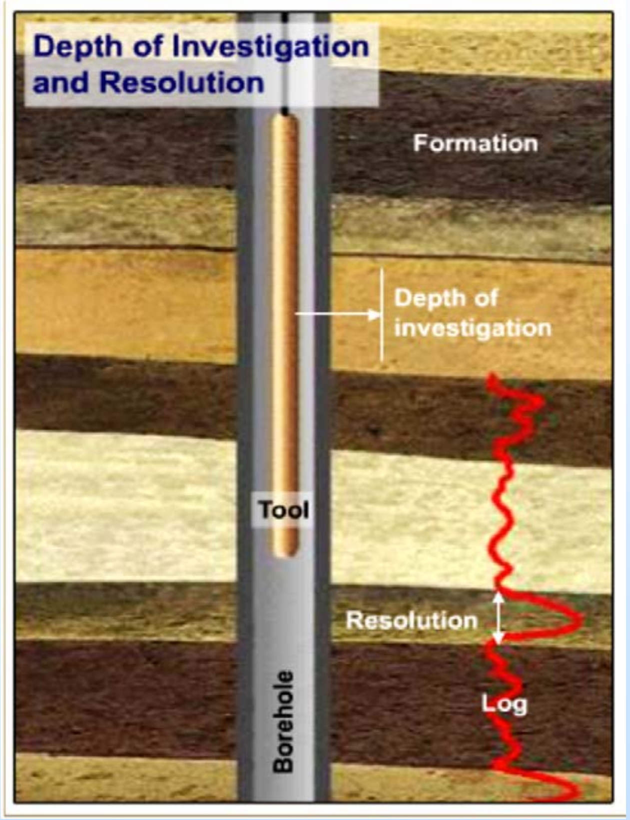
- Large number of existing wells on the dome
  - Provides extensive information on the formation tops
  - Generates a high degree of confidence in the general dome structure
- 90 wells into the Duperow top (over ~700 sq mi)
  - High confidence that the Duperow conforms to the dome structure
  - Local minima or maxima could exist – addressing with seismic
- 40 mi 8 well cross section shows good correlation in thickness and depth below Duperow top
  - Reservoir likely regionally extensive.
  - Wells are widespread and logs are different companies, older technologies so significant uncertainty in Pore, Perm, heterogeneity
  - No good sonic logs near site, so seismic inversion for density would be with low confidence
- Characterization wells reduce uncertainty

Well Locations

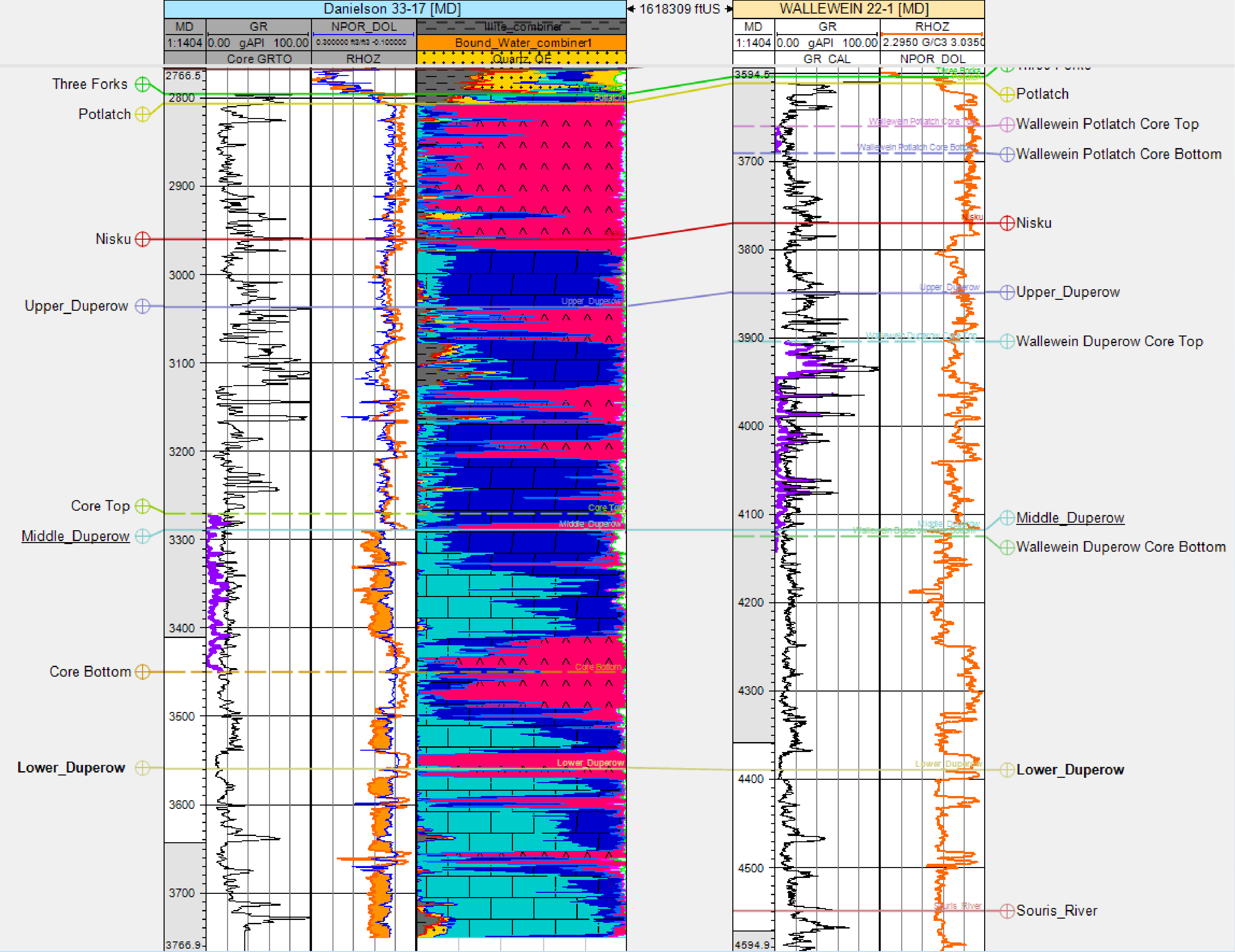



Google earth
Earth Point

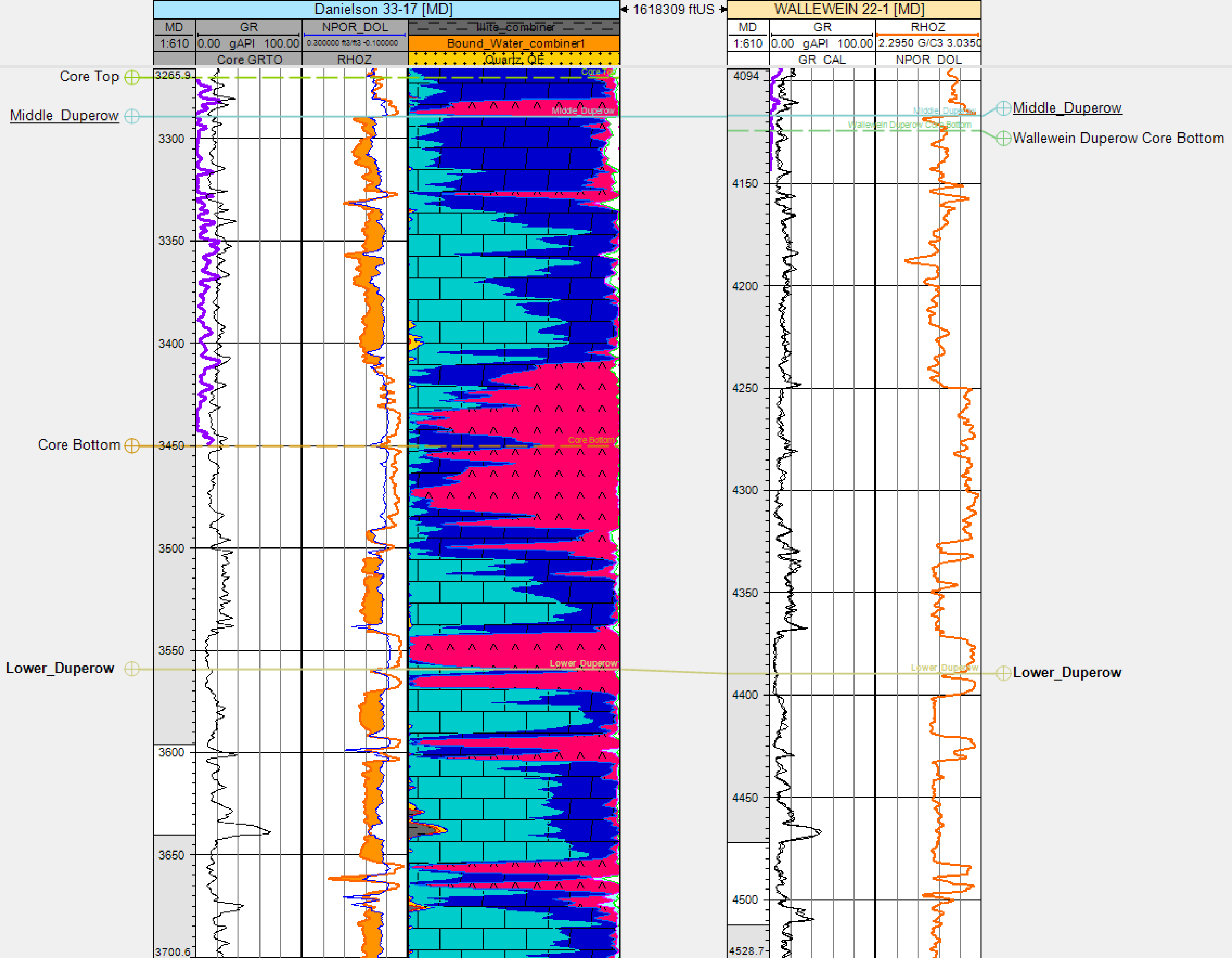
Geophysical Characterization & Monitoring: Well Logging



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

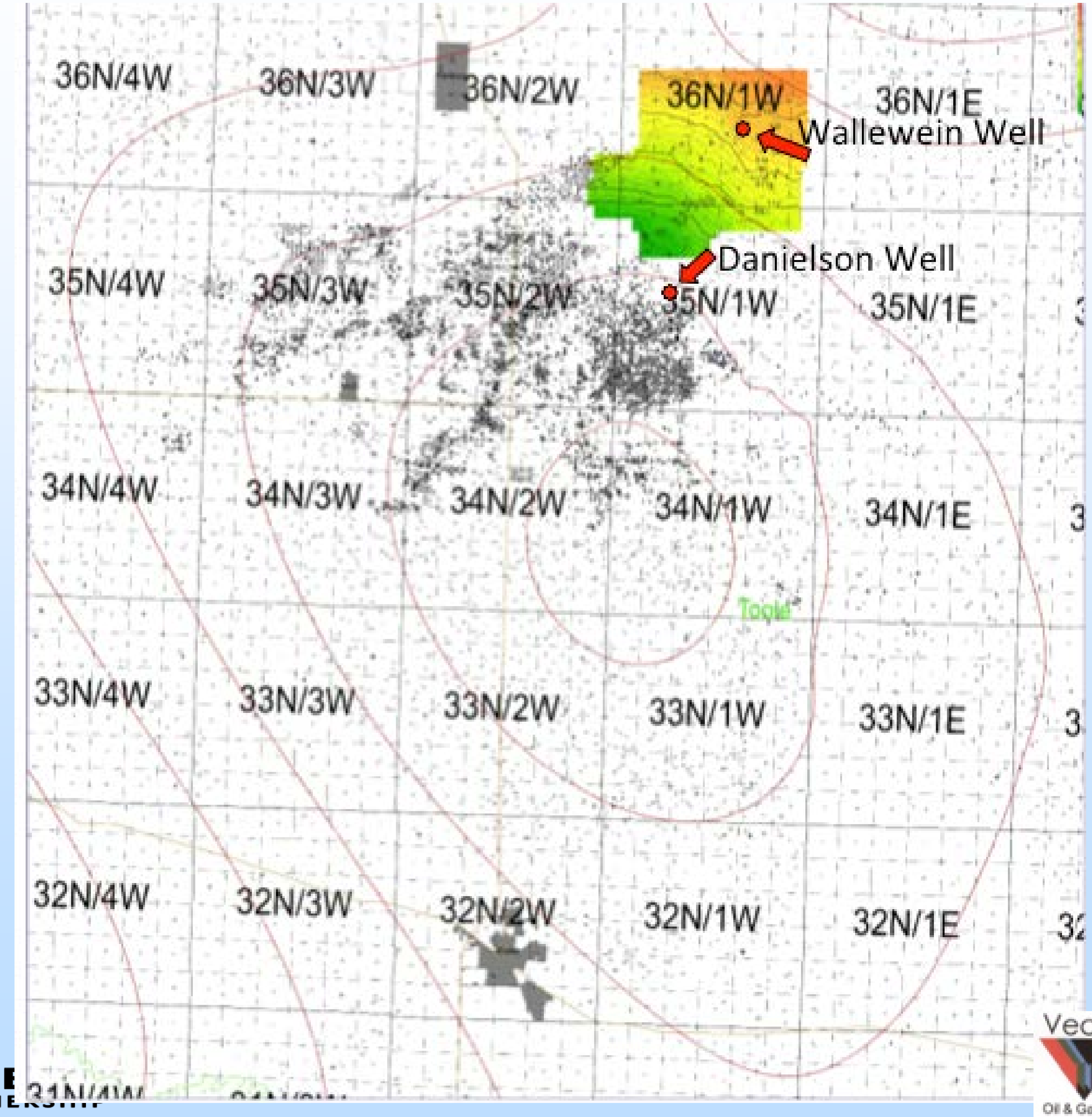


Danielson 33-17 [MD]
1618309 ftUS
WALLEWEIN 22-1 [MD]
MD
1:1404
GR
0.00 gAPI 100.00
Core GRTO
NPOR_DOL
RHOZ
Illite_combiner
Bound_Water_combiner1
Quartz_QE
GR_CAL
RHOZ
2.2950 G/C3 3.0350
NPOR_DOL
2766.5
2800
2900
3000
3100
3200
3300
3400
3500
3600
3700
3766.9
3594.5
3700
3800
3900
4000
4100
4200
4300
4400
4500
4594.9
Three Forks
Potlatch
Nisku
Upper_Duperow
Core Top
Middle_Duperow
Core Bottom
Lower_Duperow
Wallewein Potlatch Core Top
Wallewein Potlatch Core Bottom
Wallewein Duperow Core Top
Wallewein Duperow Core Bottom
Souris_River

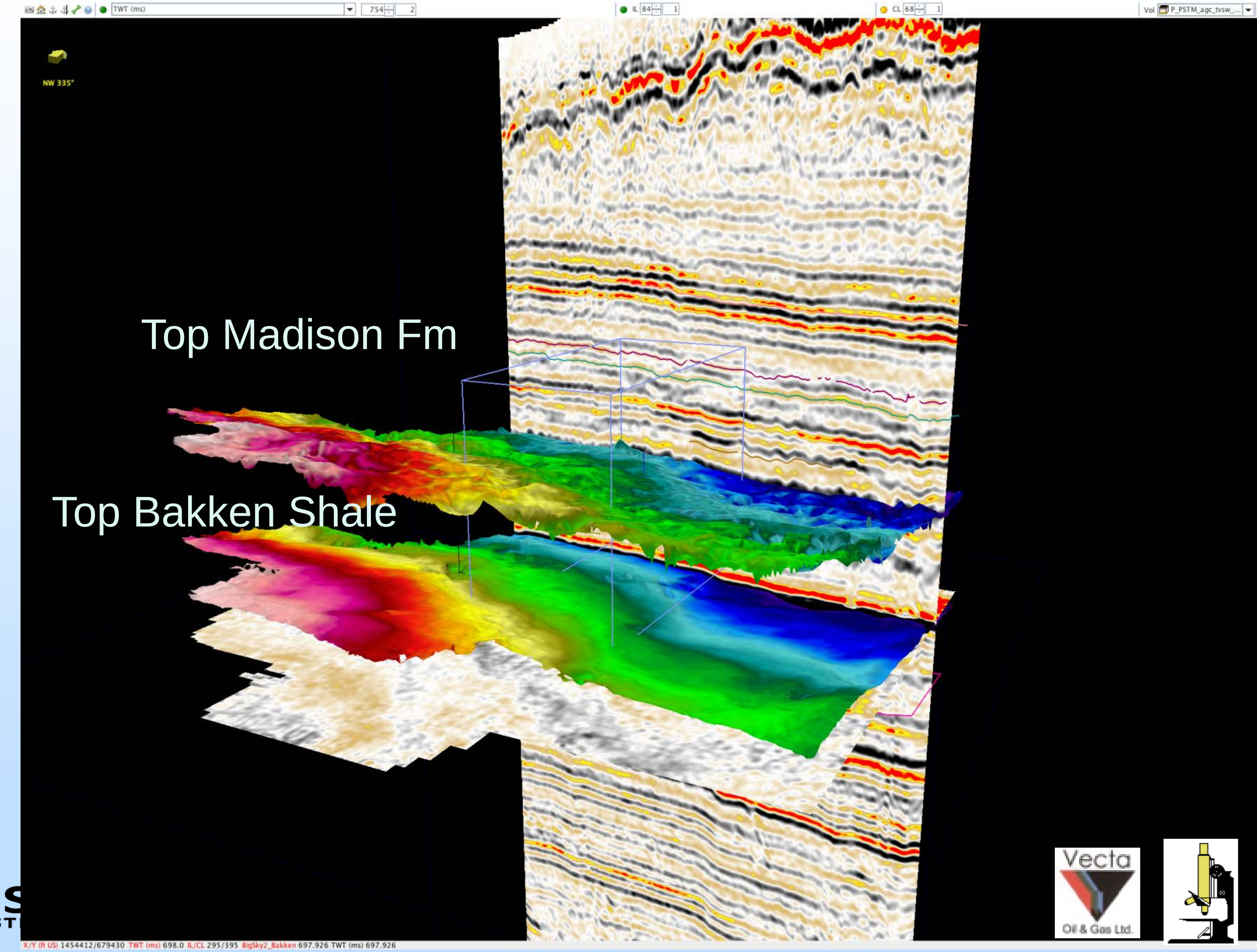


Danielson 33-17 [MD]
1618309 ftUS
WALLEWEIN 22-1 [MD]
MD
1:610
GR
0.00 gAPI 100.00
Core GRTO
NPOR_DOL
RHOZ
Illite_combiner
Bound_Water_combiner1
Quartz_QE
GR CAL
RHOZ
2.2950 G/C3 3.0350
NPOR_DOL
Core Top
Middle_Duperow
Core Bottom
Lower_Duperow
Wallewein Duperow Core Bottom
3265.9
3300
3350
3400
3450
3500
3550
3600
3650
3700.6
4094
4150
4200
4250
4300
4350
4400
4450
4500
4528.7

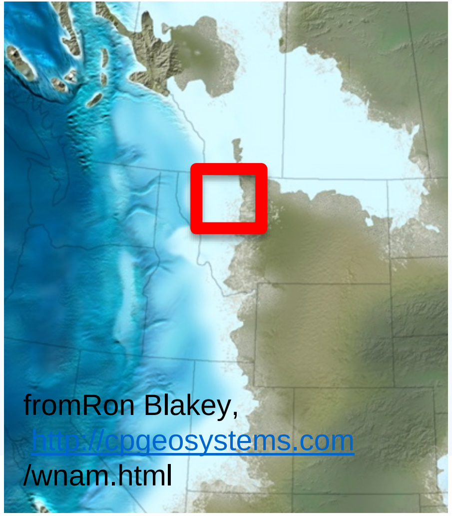
Structure Top Duperow from Well Control and Structure Top Bakken Shale from Seismic

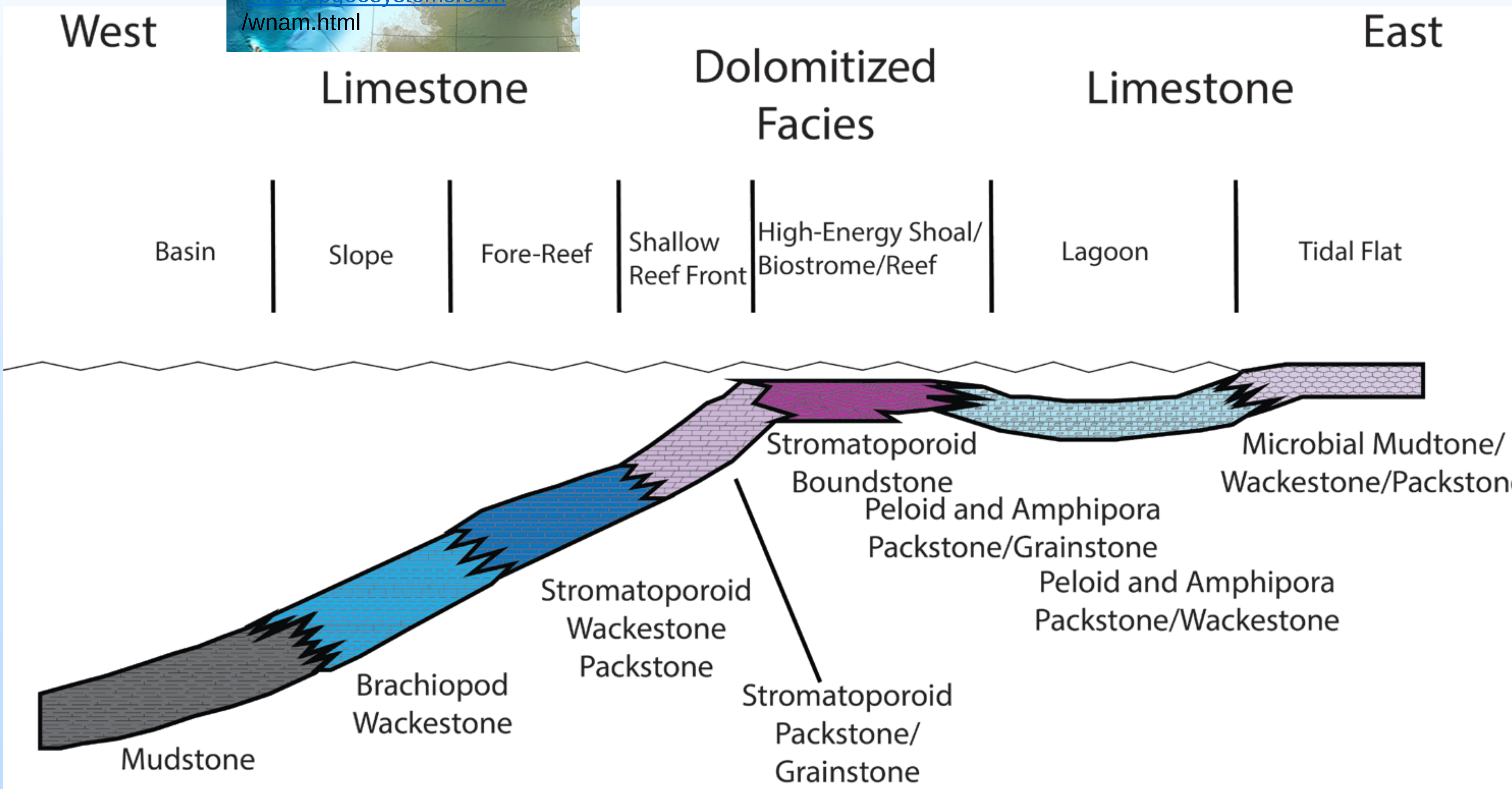


Structural Surfaces BSCSP 3D-Survey

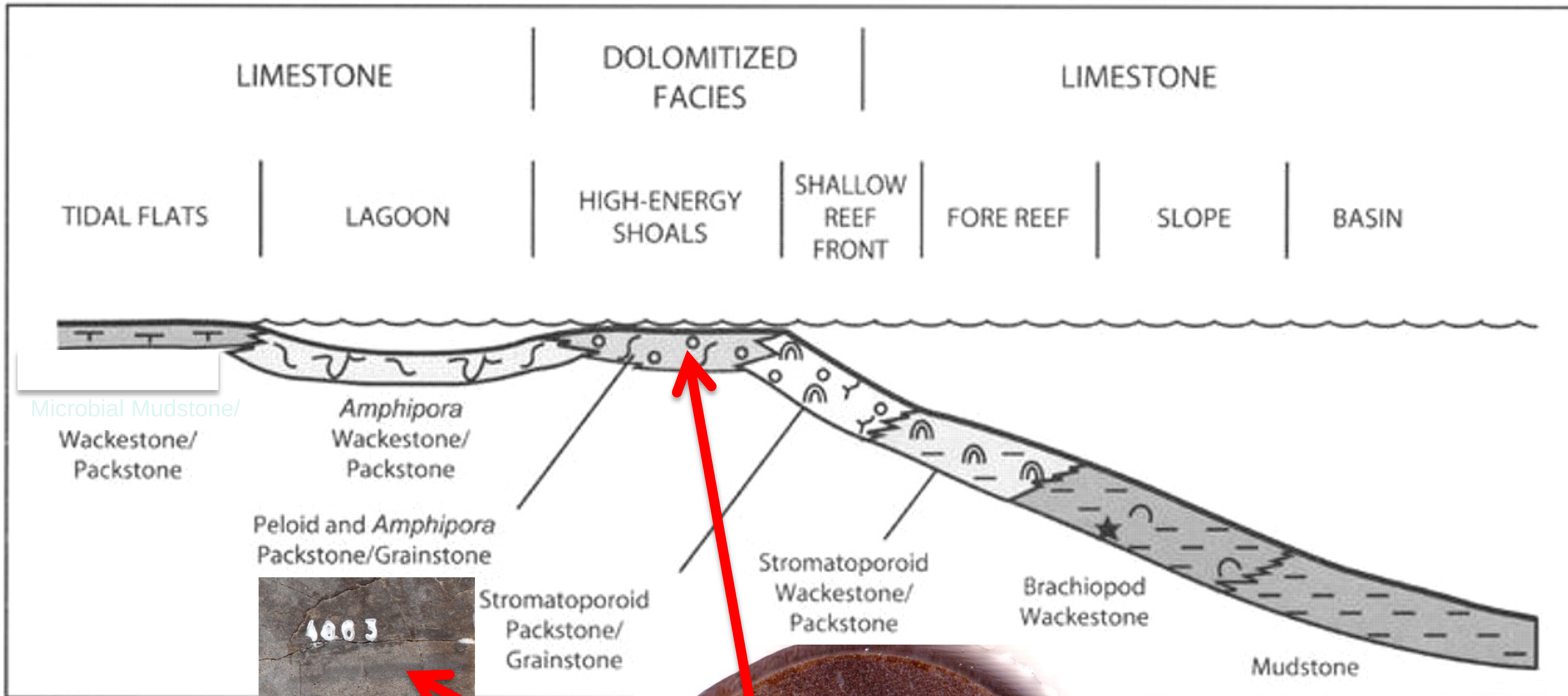


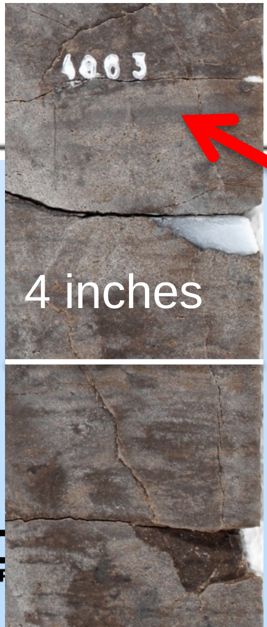
Duperow Facies Model



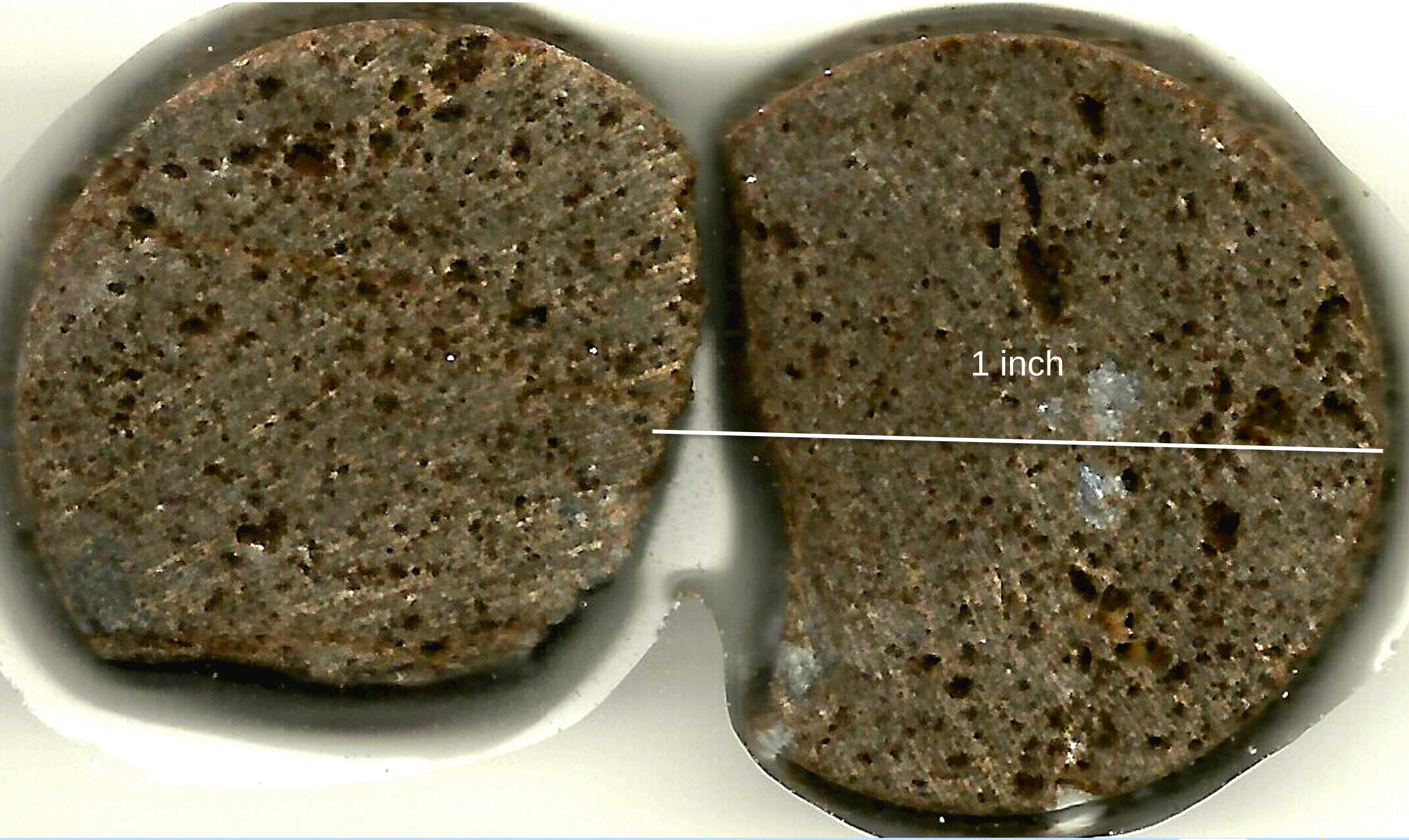


WALLEWEIN: 4063.1 ft.: High-Energy Shoal

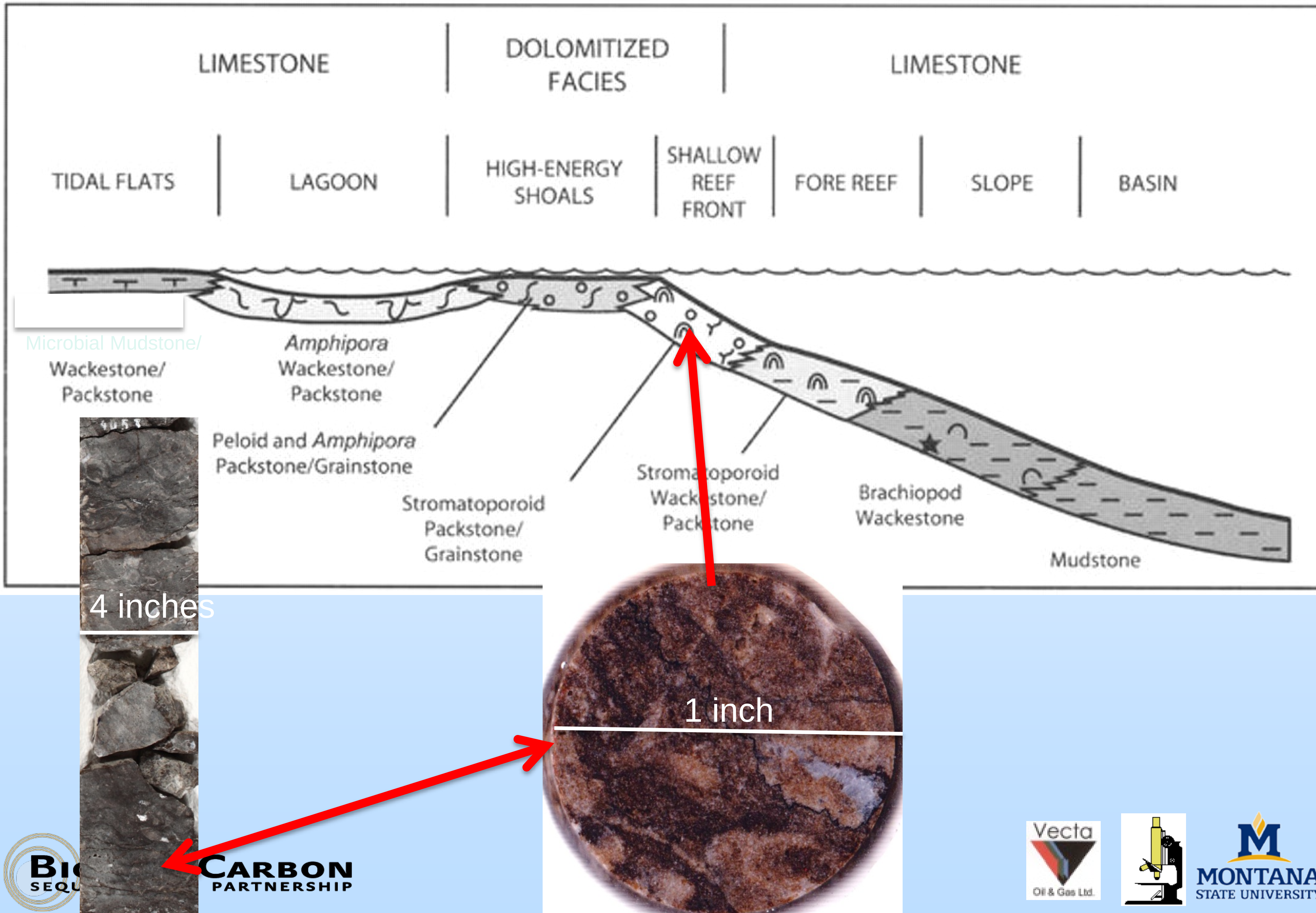




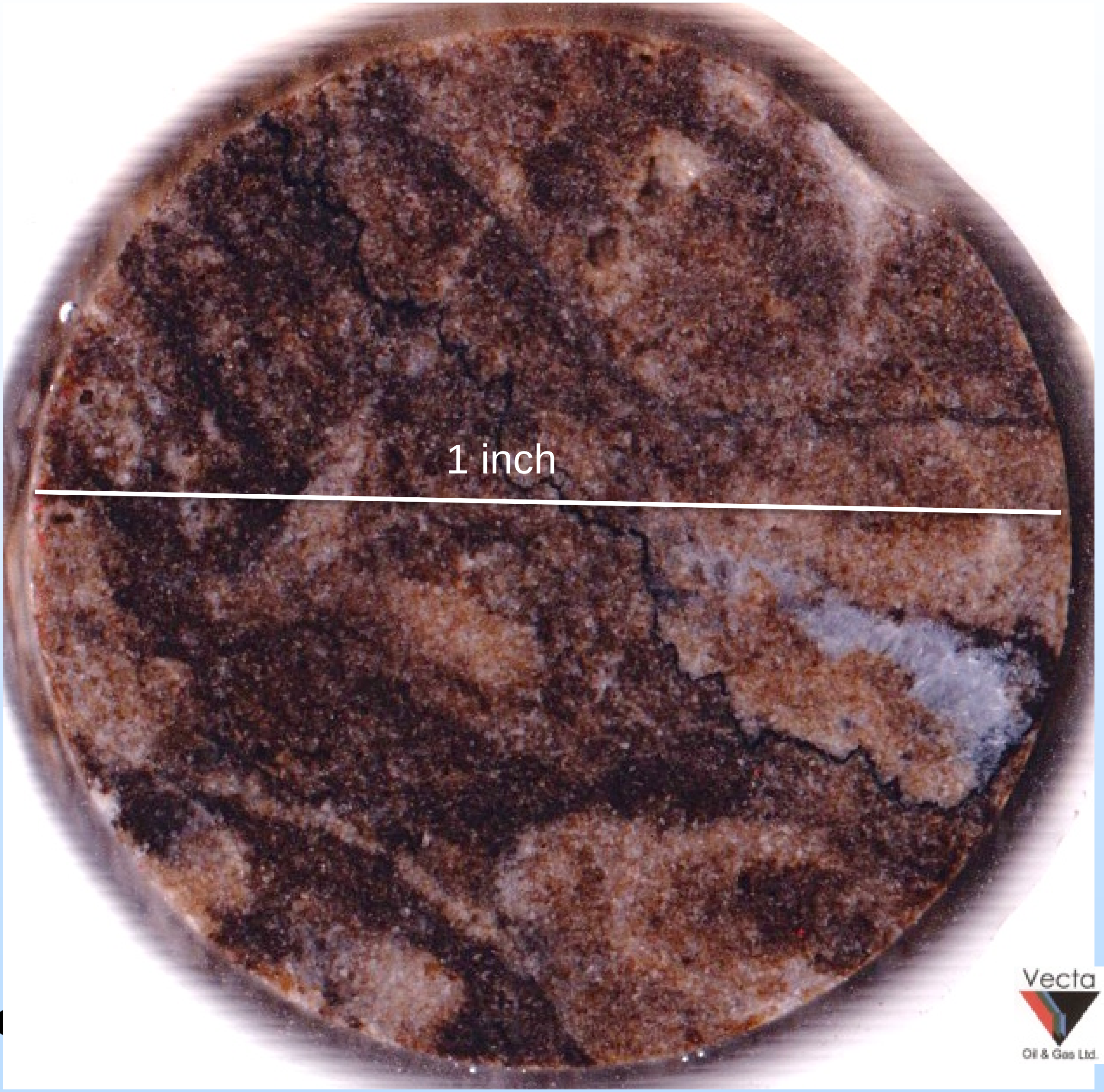
DANIELSON 33-17: 3296.23 ft.: Coarse Grainstone



WALLEWEIN: 4053.9 ft.: Stromatoporoid Reef



WALLEWEIN: 4053.9 ft.
Stromatoporoid Reef Porosity



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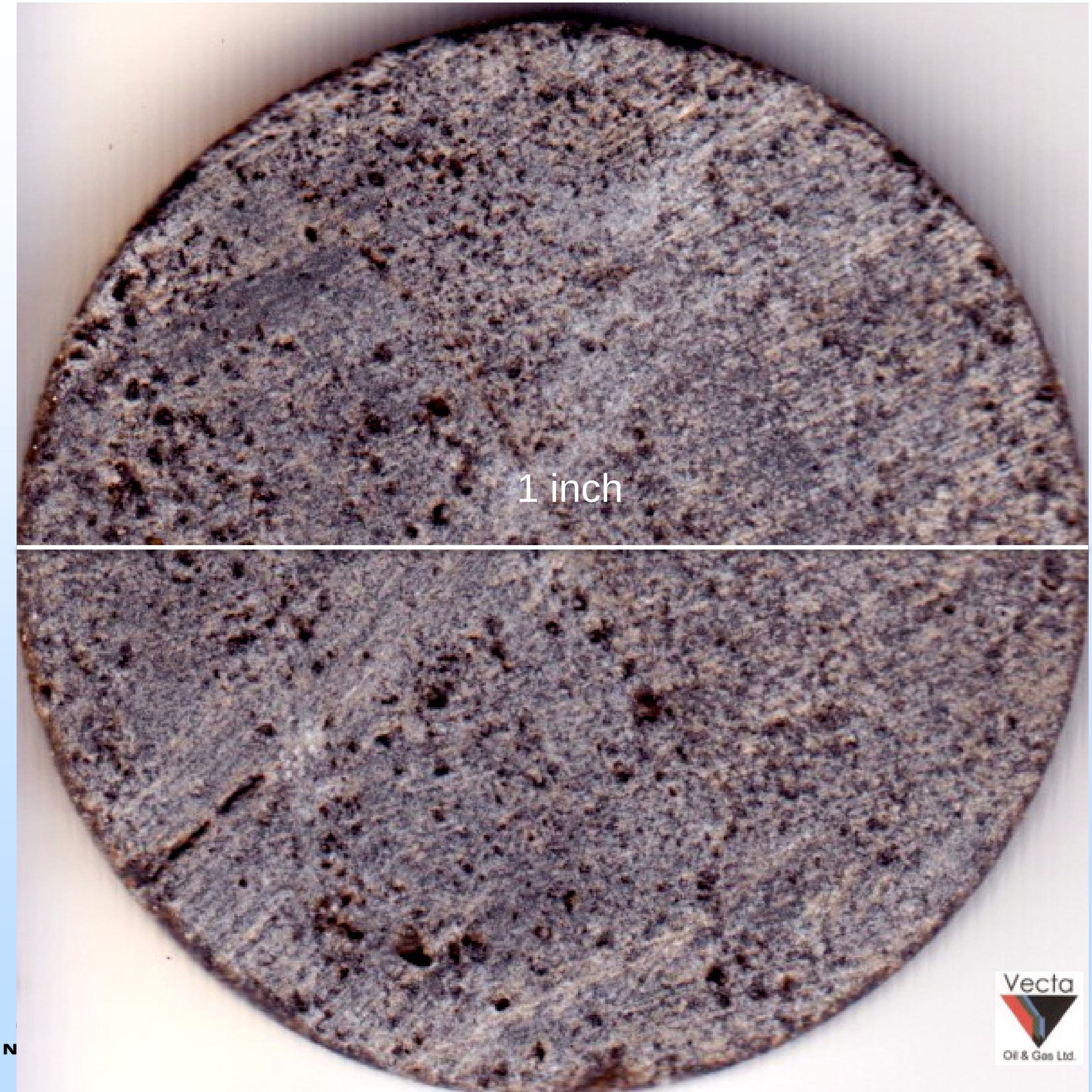
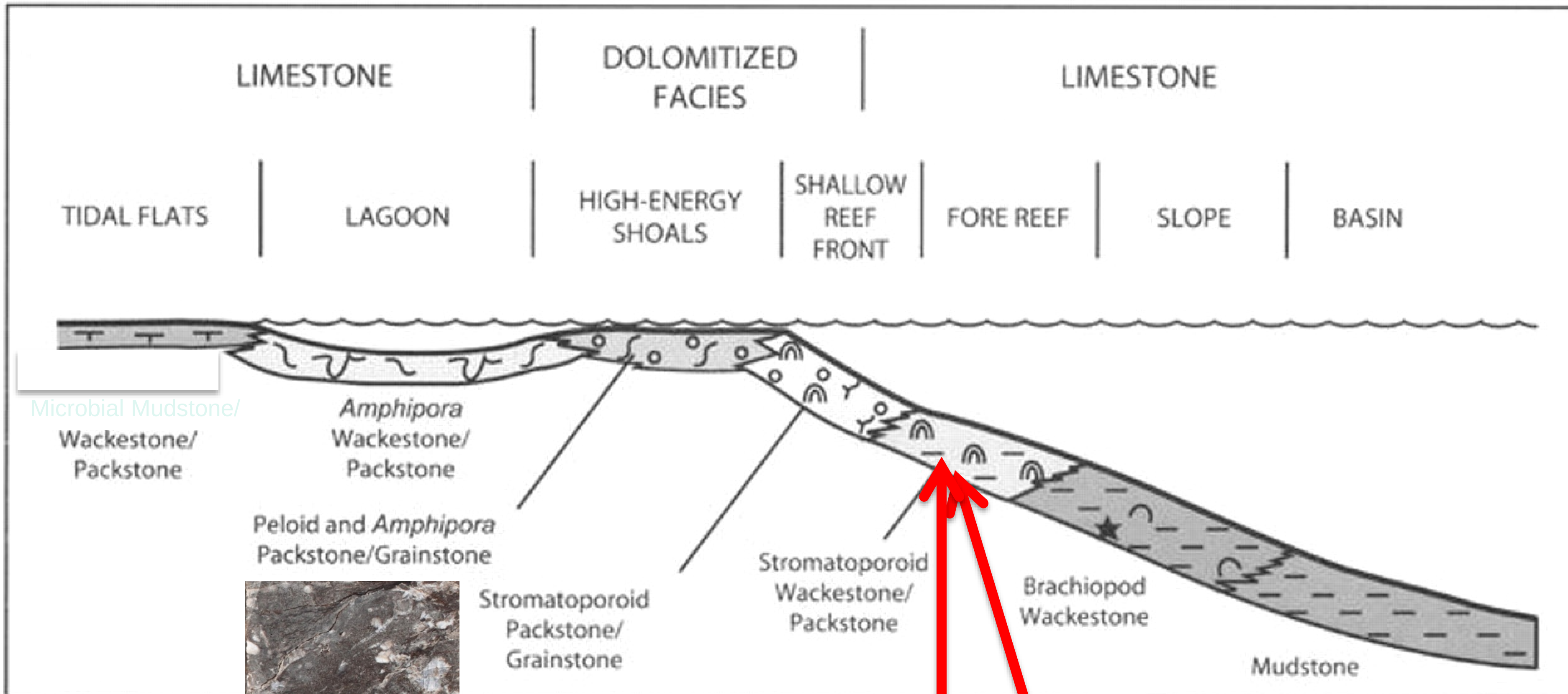
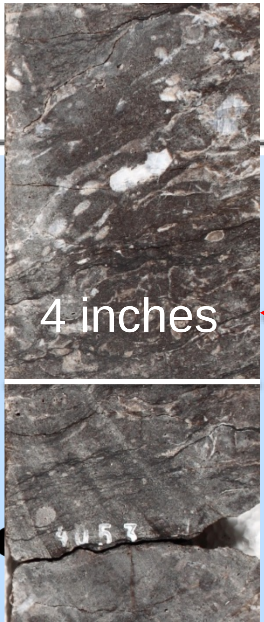
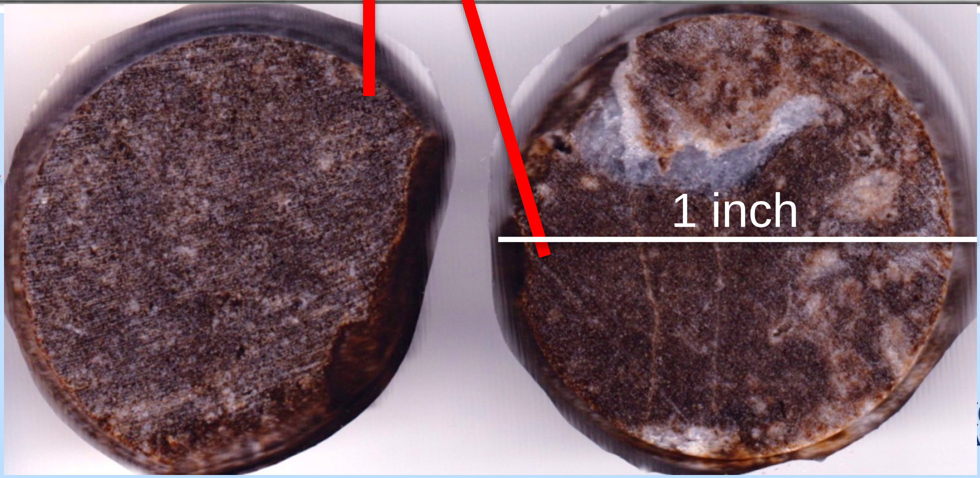
WALLEWEIN: 4123.9 ft.: Stromatoporoid Reef Porosity



WALLEWEIN: 4052.8 ft.:Stromatoporoid Fore-Reef







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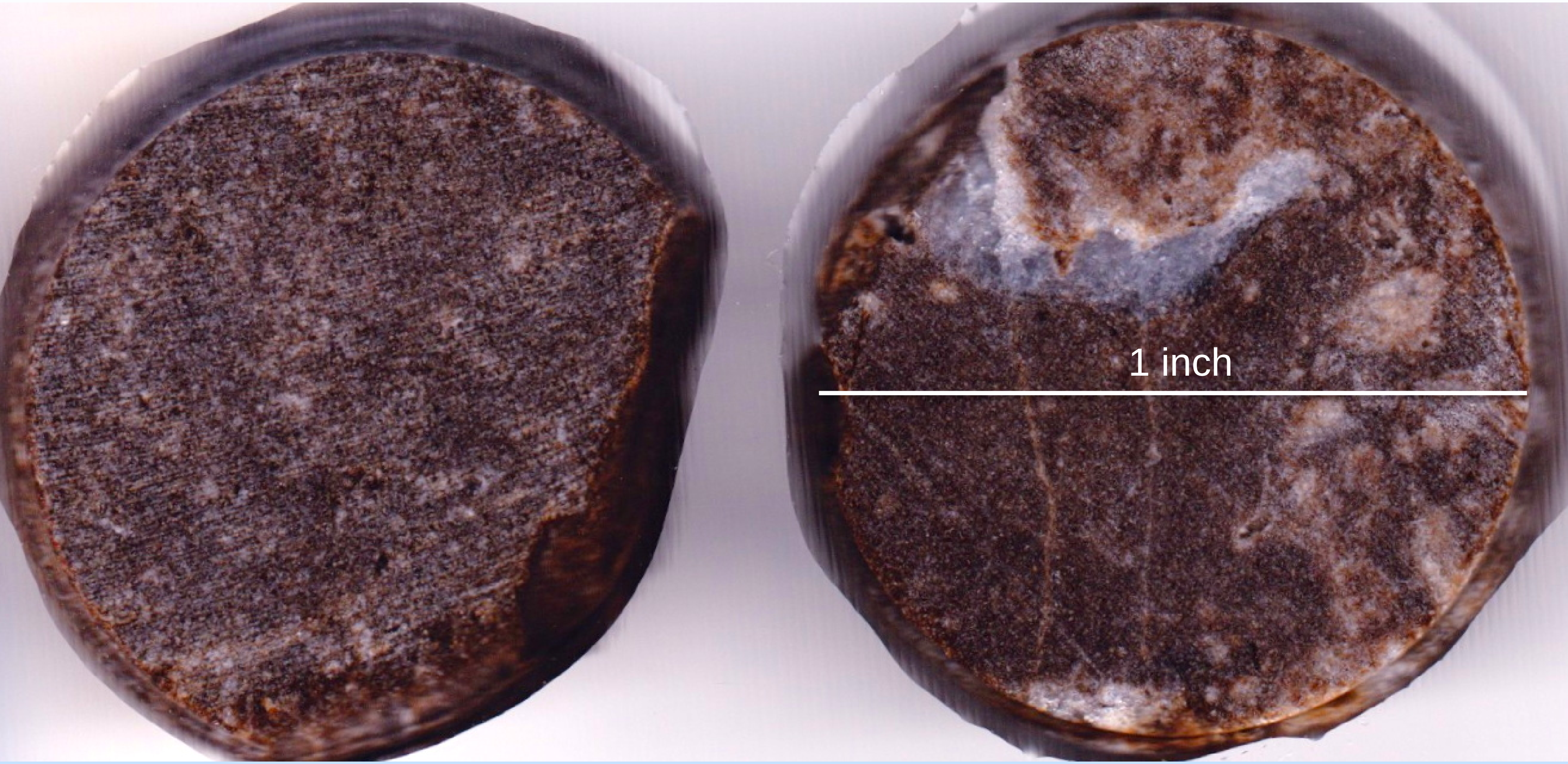
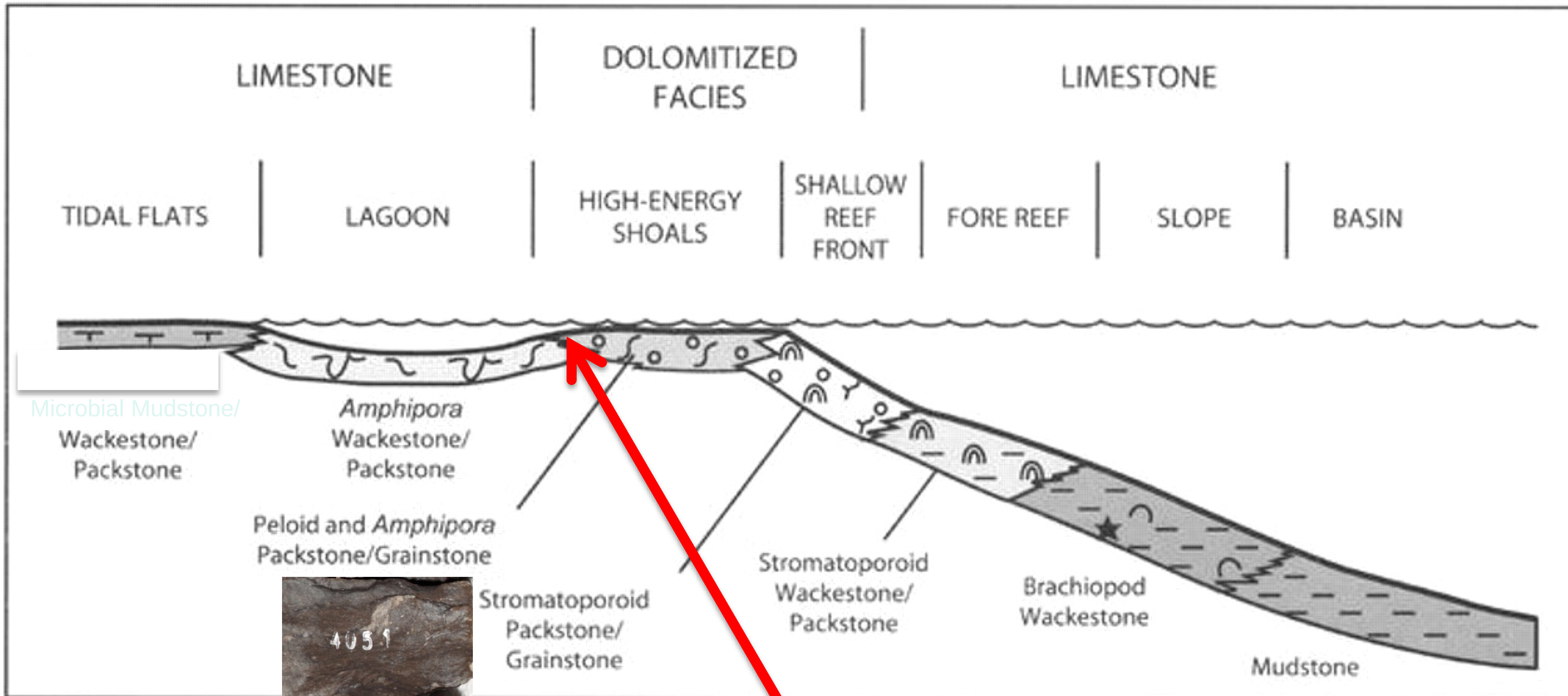
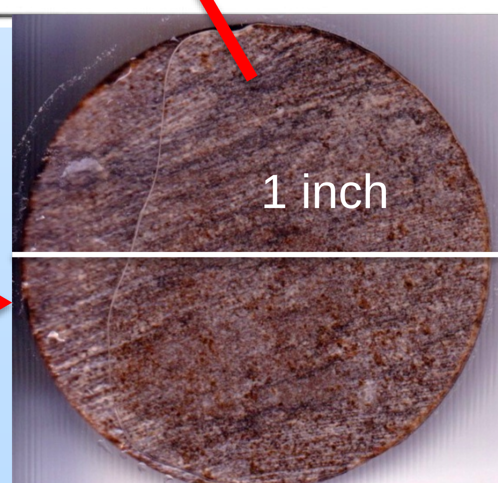
WALLEWEIN: 4052.8 ft.: Stromatoporoid Fore-Reef

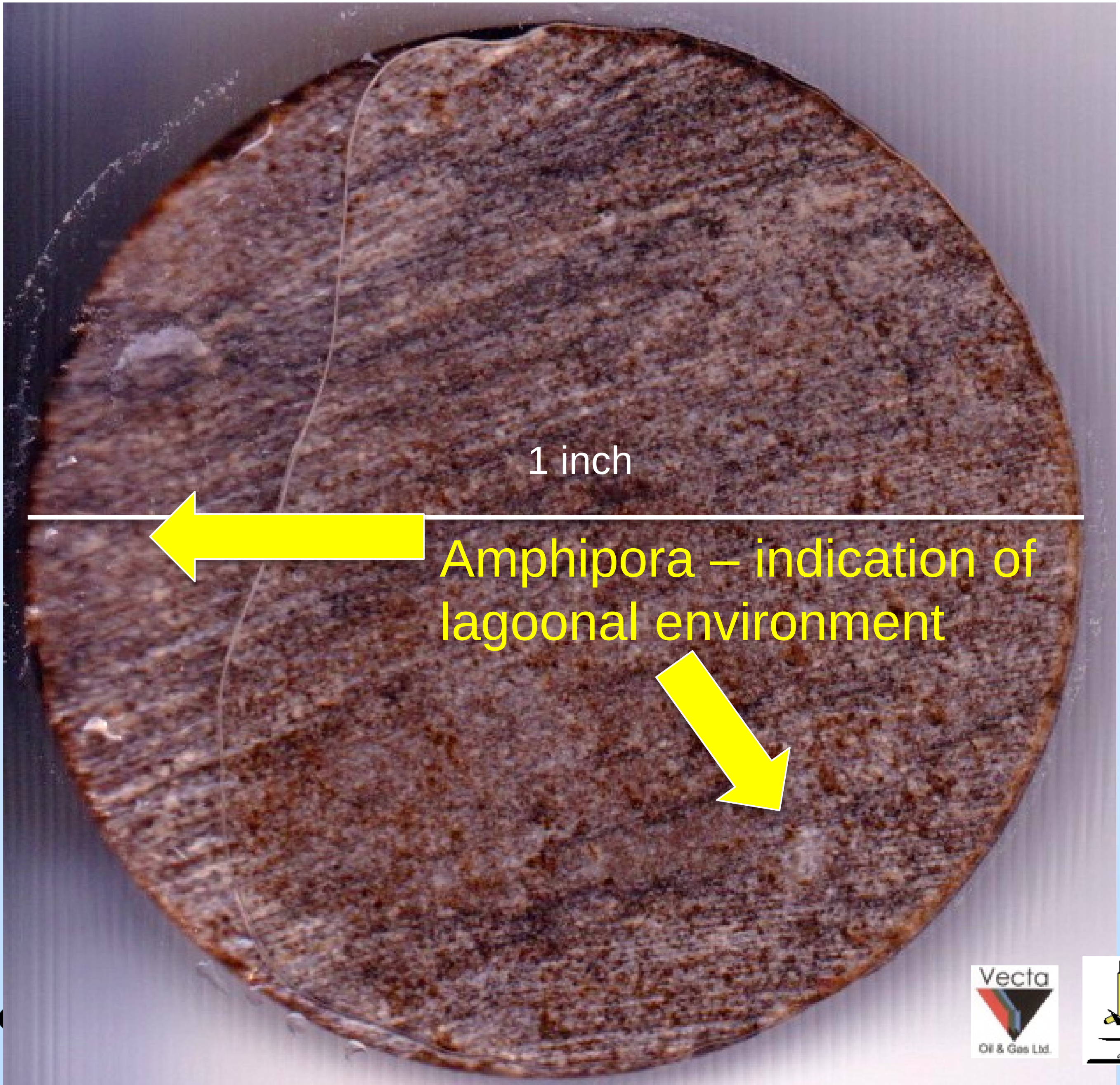


WALLEWEIN: 4051.4 ft. Back-Shoal





WALLEWEIN: 4051.4 ft. Back-Shoal

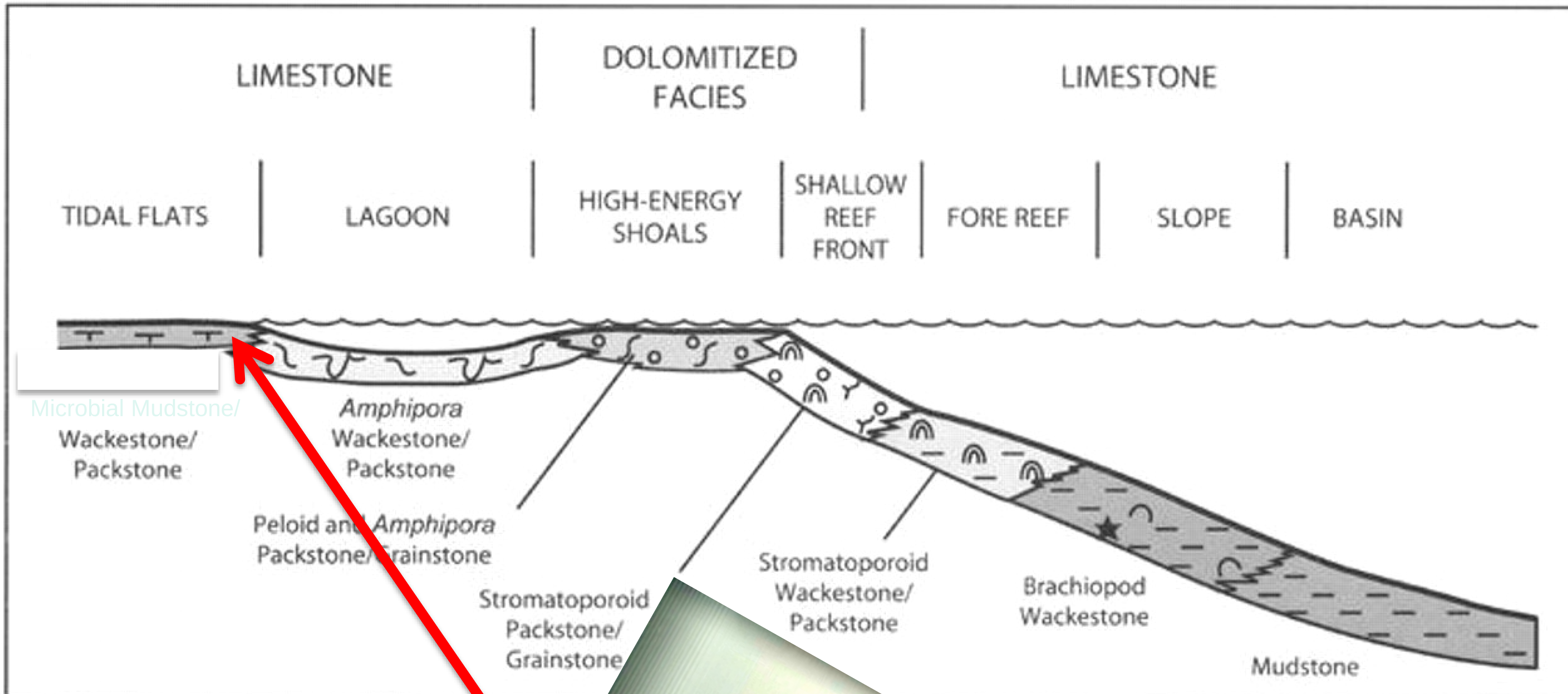


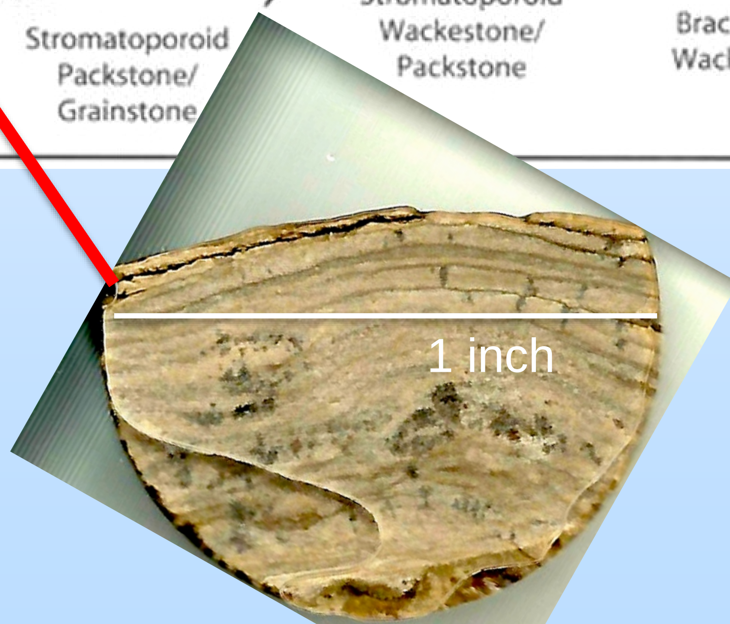
BIG SKY SEQUESTRATION

Vecta Oil & Gas Ltd.

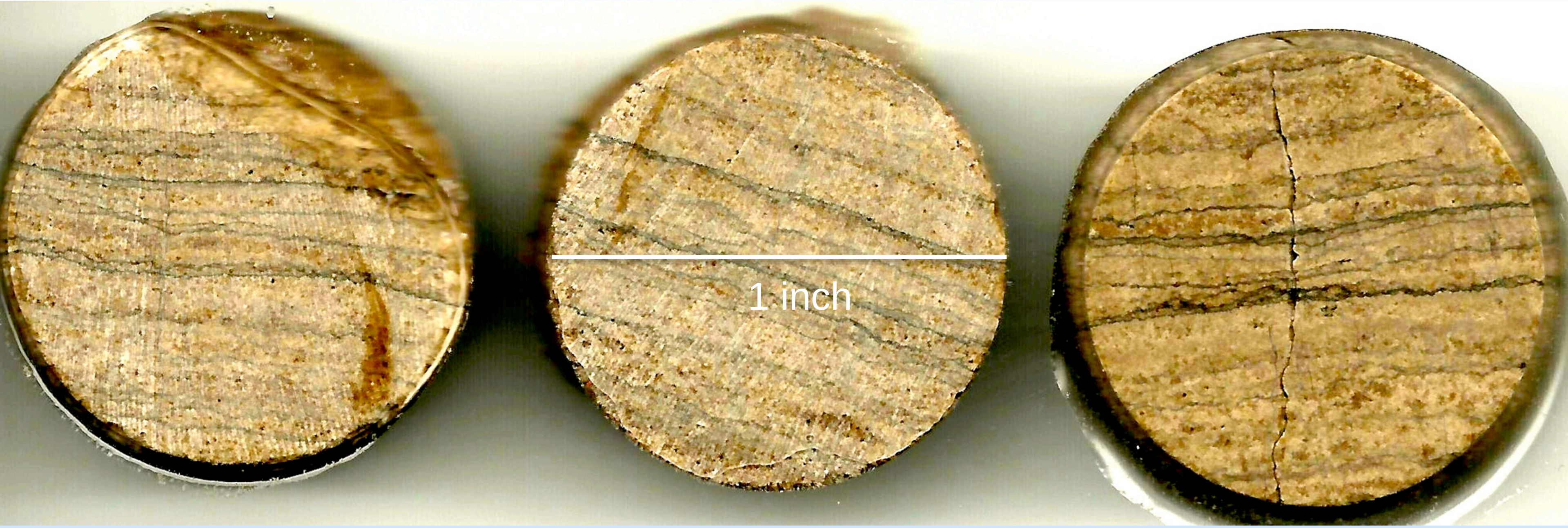
MONTANA STATE UNIVERSITY

WALLEWEIN: 3979.12 ft. Tidal Flat





DANIELSON 33-17: 3291.50 ft.: Microbialites



Big Sky Carbon
Sequestration Partnership

Vecta
Oil & Gas Ltd.

Montana State University

WALLEWEIN: 3979.12 ft.
POROUS MICROBIALITES

Big Sky Carbon Sequestration Partnership

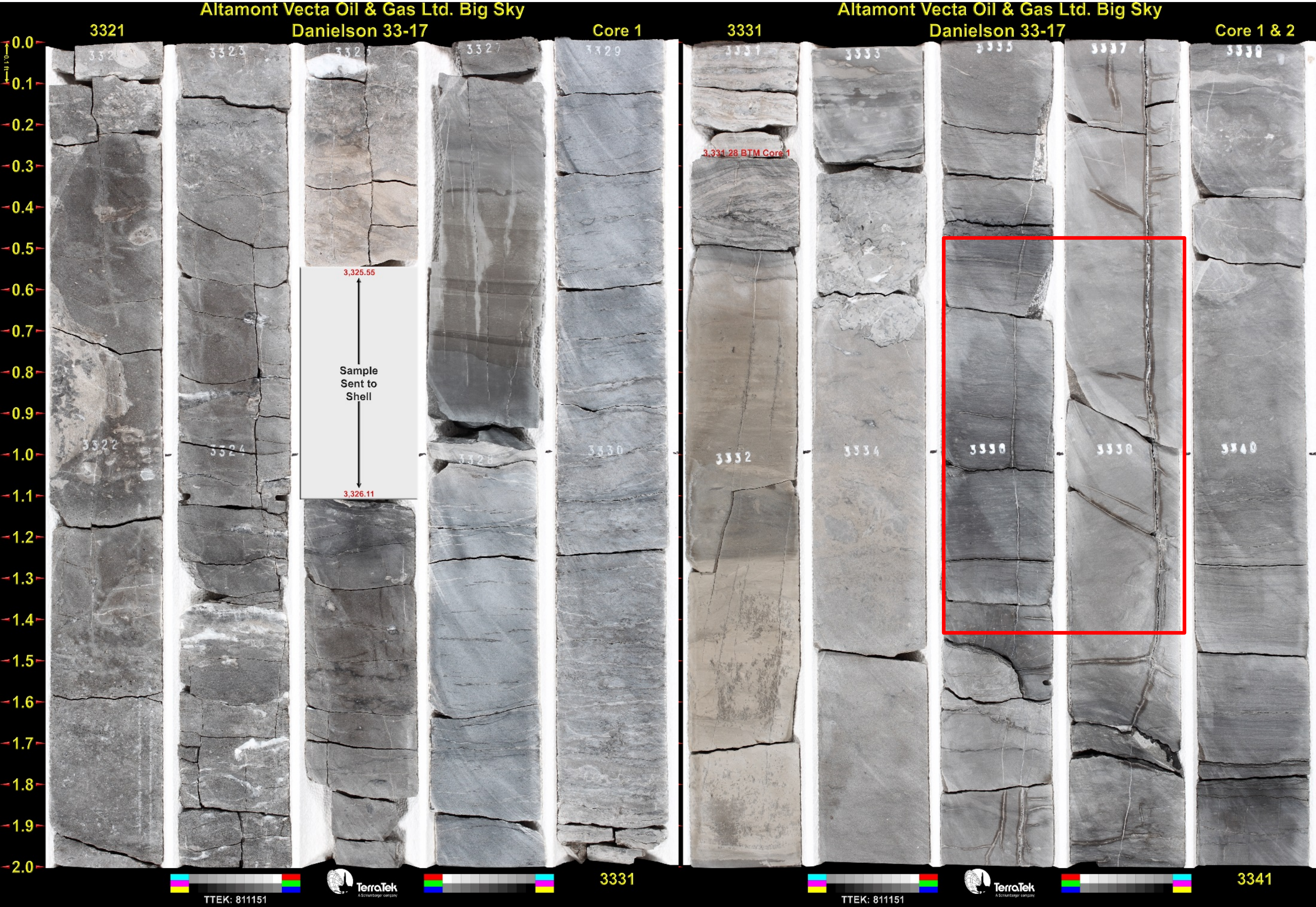
Vecta Oil & Gas Ltd.

Montana State University

Key Points

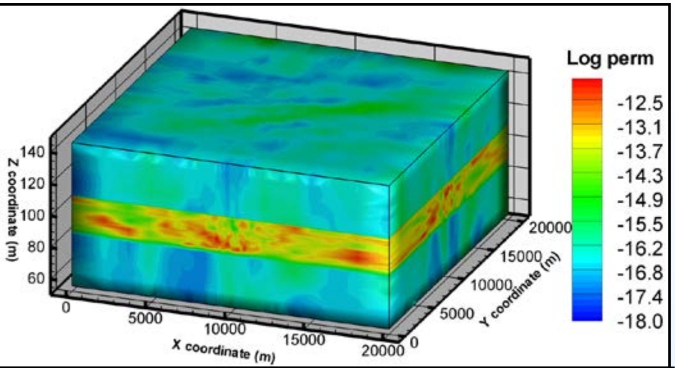
- Seismic indicates that structure conforms to the original mapping and no major faults are present in the injection area.
- Modern log suites from the production area and injection area demonstrate rock units in the reservoir intervals are very continuous and correlate extremely well over 7 miles.
- Core and log data indicate very good reservoir properties consistent over large regions.
- Natural fracturing is present but is bedding constrained and confined to the reservoir interval.
- Core from the Potlatch Anhydrite and the Upper Duperow caprock demonstrate the mechanical integrity of both intervals.

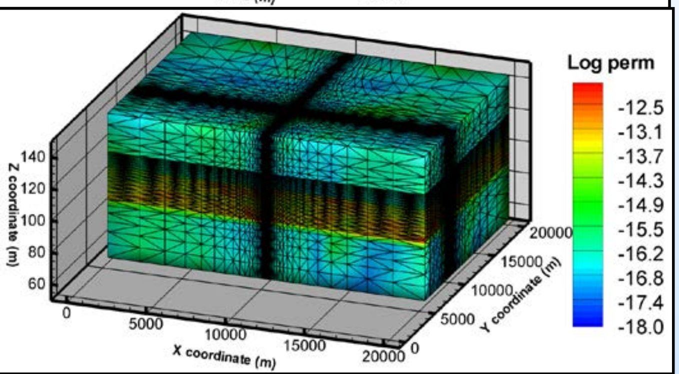
Middle Duperow – Fractures



Middle Duperow – Fractures Propped by Precipitates

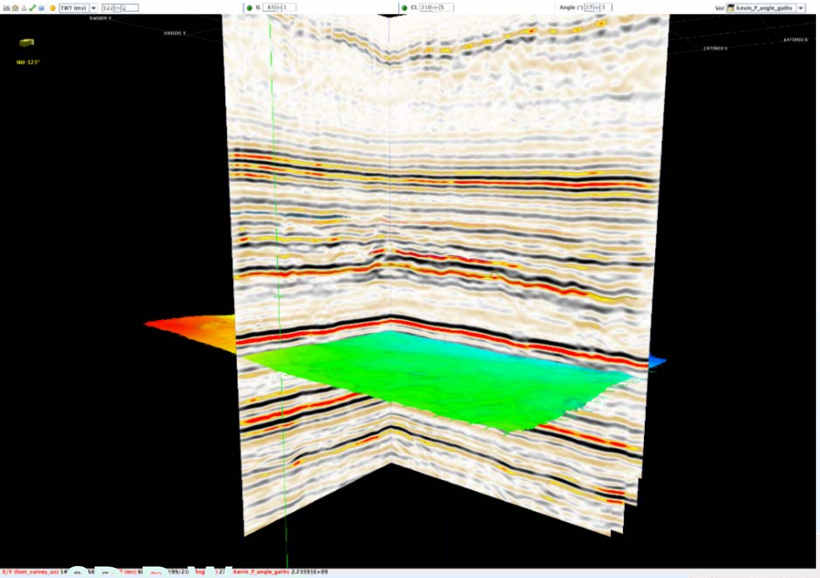
How will data change confidence level?



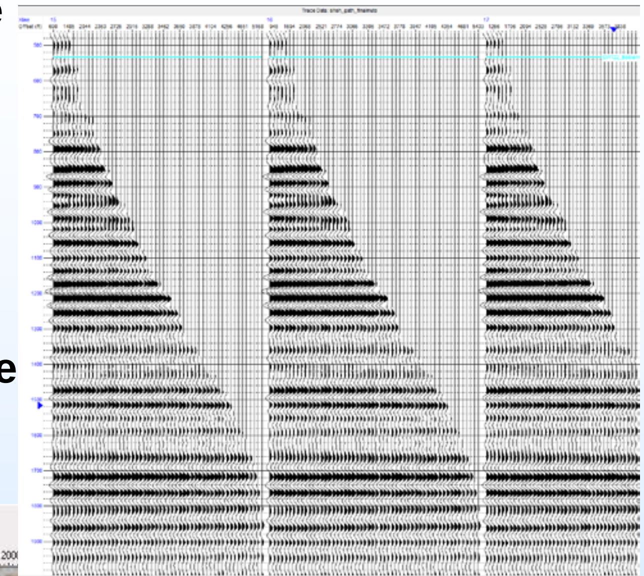


- Logs indicate some higher porosity regions of (up to 20%), which is higher than used in the injectivity modeling
- Highest permeability thickness is greater than in the model (40m vs 20m).
- Correlation is very good which may indicate less heterogeneity and narrower distribution in the horizontal direction for pore – perm than used in the model. (Model used vertical distribution for overall distribution).
- Confidence level for injectivity increases very substantially.

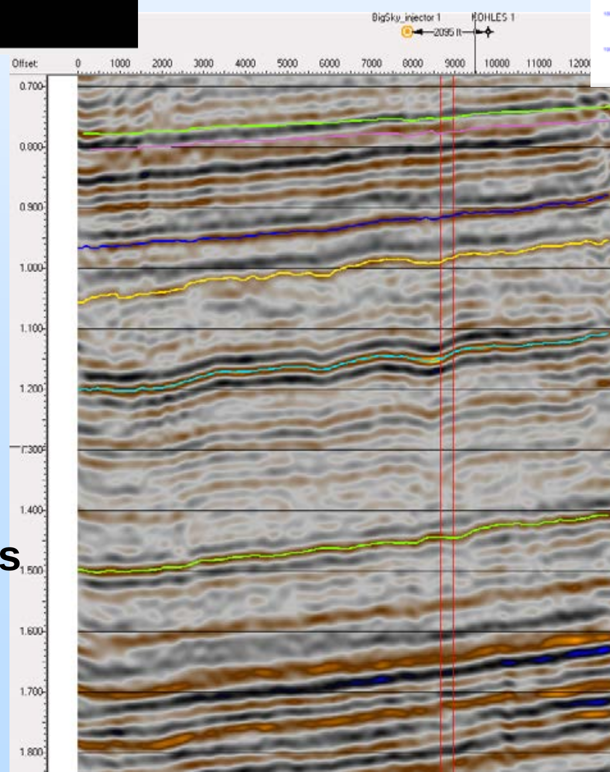
BSCSP Seismic Monitoring Program



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

Big Sky Carbon Sequestration Partnership

Vecta Oil & Gas Ltd.

Montana State University

THE LEADING EDGE OCTOBER 1998, p 1396

Dynamic reservoir characterization of Vacuum Field

DANIEL J. TALLEY, Chevron North American Exploration and Production, New Orlea
THOMAS L. DAVIS and ROBERT D. BENSON, Colorado School of Mines
STEVEN L. ROCHE, Input/Output, Sugar Land, Texas

Time-lapse multicomponent seismic surveying enables dynamic reservoir characterization and the production of a dynamic reservoir model. This, in turn, assists in producing structured economic and technical decisions that will extend reservoir life and improve recovery while reducing risk and environmental impact.

This article briefly describes the

S-waves enable the discrimination of rock and fluid properties, their characteristics, and their changes over time.

When combined into time-lapse multicomponent (4-D, 3-C) seismology, the resulting method is a tool for volume resolution: i.e., it provides the ability to sense changes in the bulk rock/fluid properties of the

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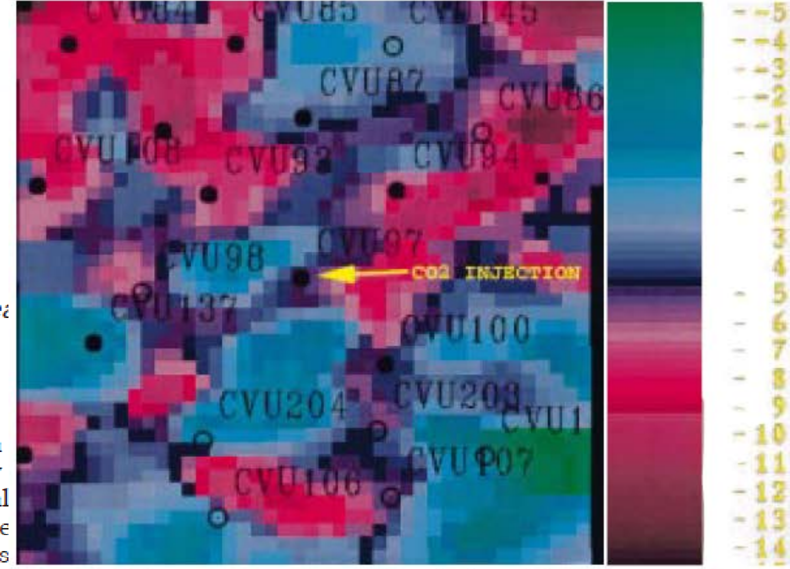


Figure 5. Velocity anisotropy map from the base 3-D, 3-C survey. The area south of the CO_2 injection shows values of near zero percent anisotropy, indicating vertical open fractures both parallel and perpendicular to the maximum horizontal stress field.

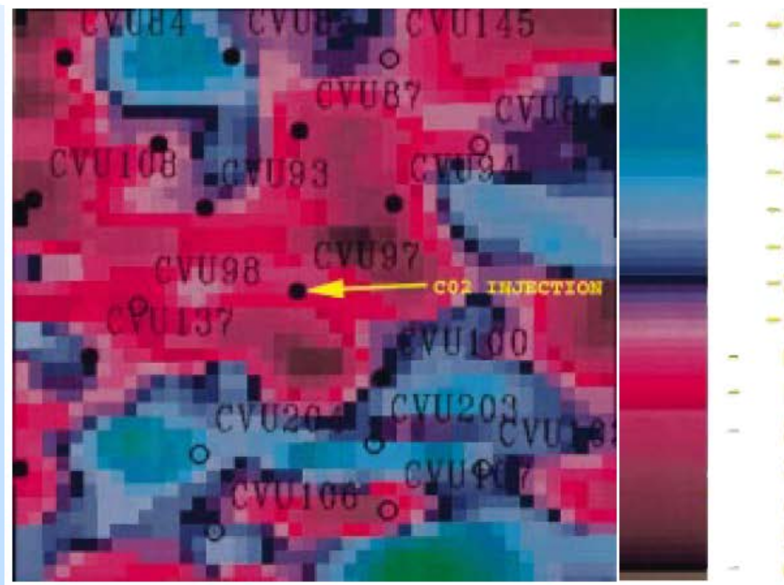


Figure 6. Velocity anisotropy map from the repeat 3-D, 3-C survey. The zone of zero percent anisotropy from the base survey is now showing 6% positive anisotropy, indicating a higher density of vertical open fractures parallel to the maximum horizontal stress direction or stiffening of the frame due to viscosity and/or saturation change of the fluid and a reduction in bulk density.

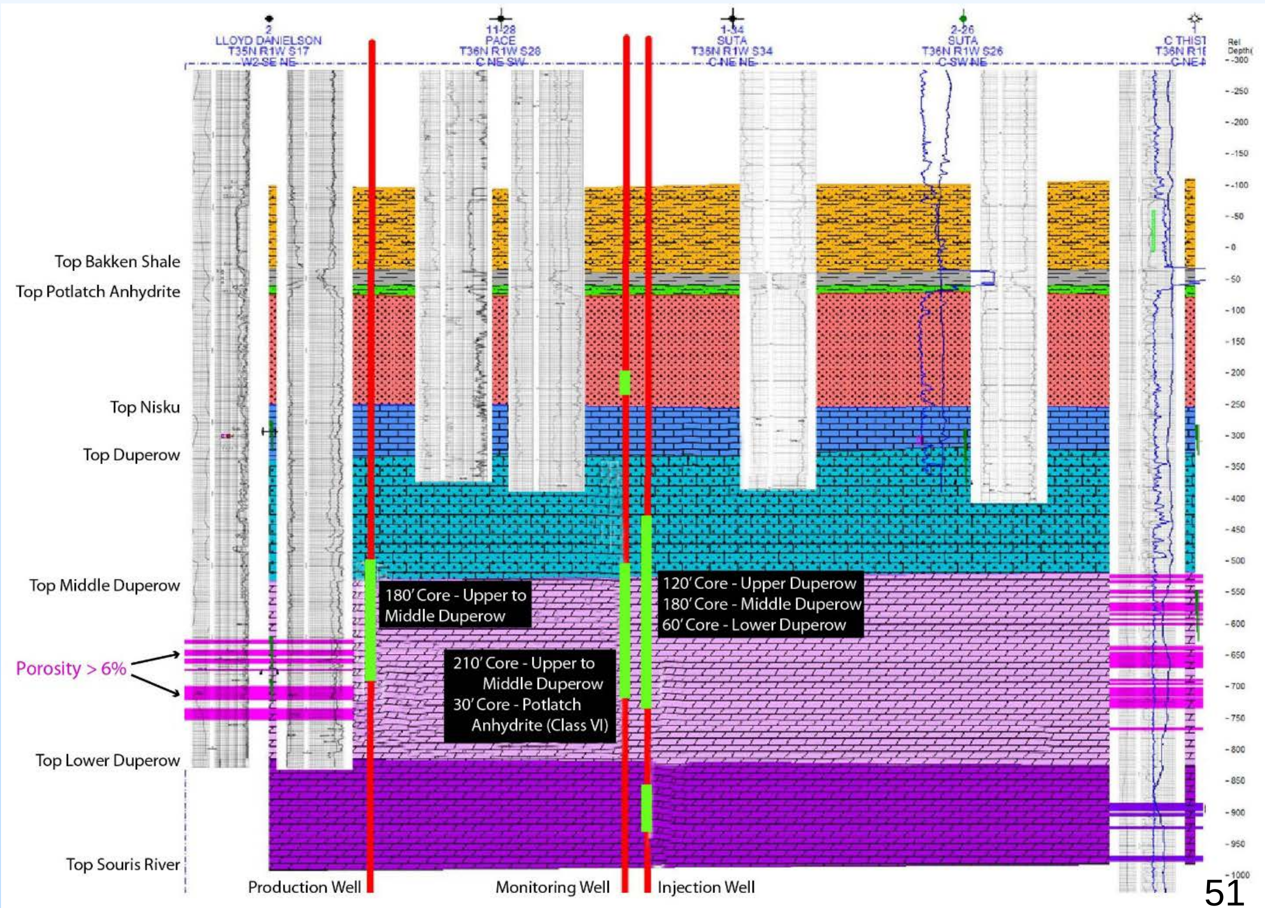
"The shear-waves responded to a change in pore aspect ratio or preferential opening of microfractures resulting from the injection of CO_2. The faster shear-wave (S1) velocity was attenuated less with the resulting change in low-aspect ratio crack porosity."

Site Characteristics – Scientific Opportunities

- Reservoir is in stiff, fairly brittle rock with existing fractures (1-2 ft vert.)
- Reservoir has interbedded anhydrites
  - Brittle rock potentially represents good opportunity to study geomechanics
  - Stacks with alternate plastic rocks and thick anhydrite seal make this an extremely safe place to investigate geomechanical effects
- Multi-component seismic can be used to investigate response of fractured reservoir to pressure changes
-

Core Plan – Planned Analyses

Porosity
Permeability (horizontal, vertical, relative)
Capillary pressure (mercury injection)
Core flood, geochemical reactivity
Seismic properties, anisotropy analysis
Tight rock analysis (pulse decay permeability, grain density, saturations)
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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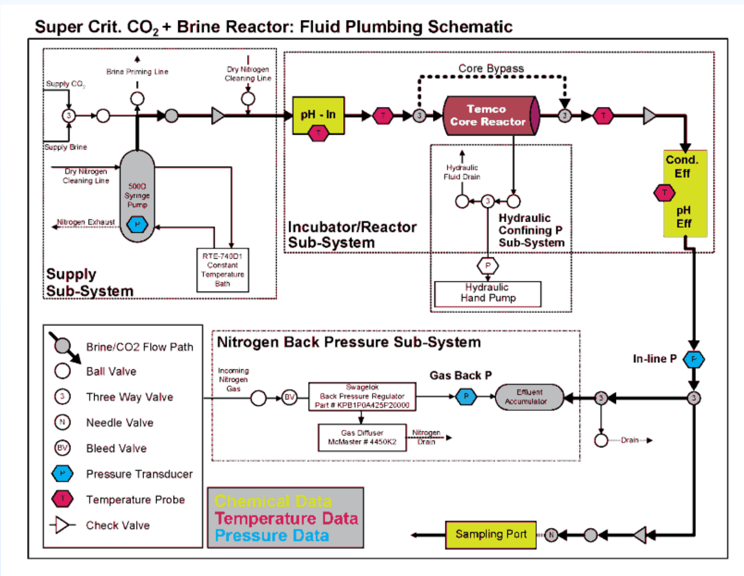
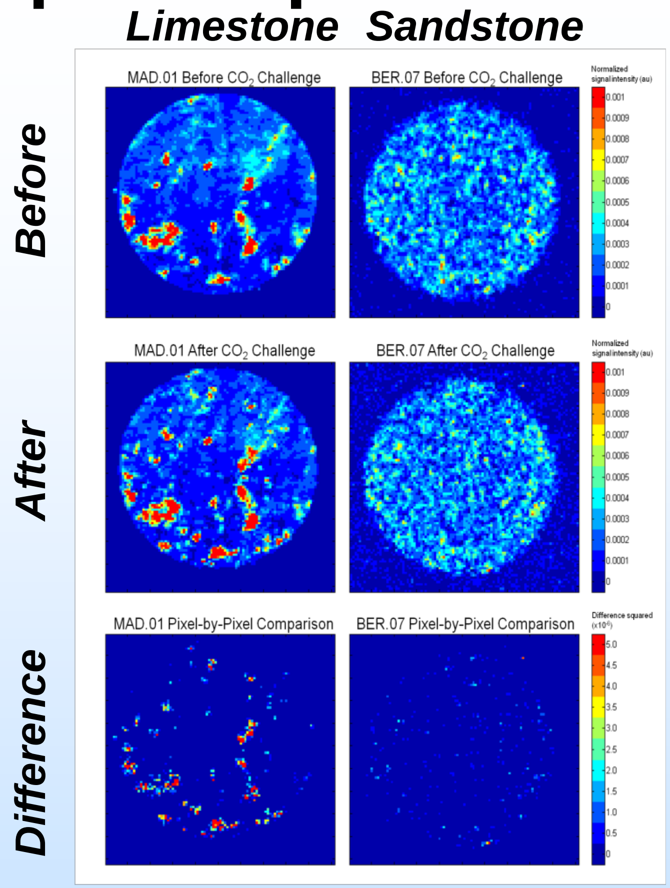
Core Testing: Reactive Transport Experiments



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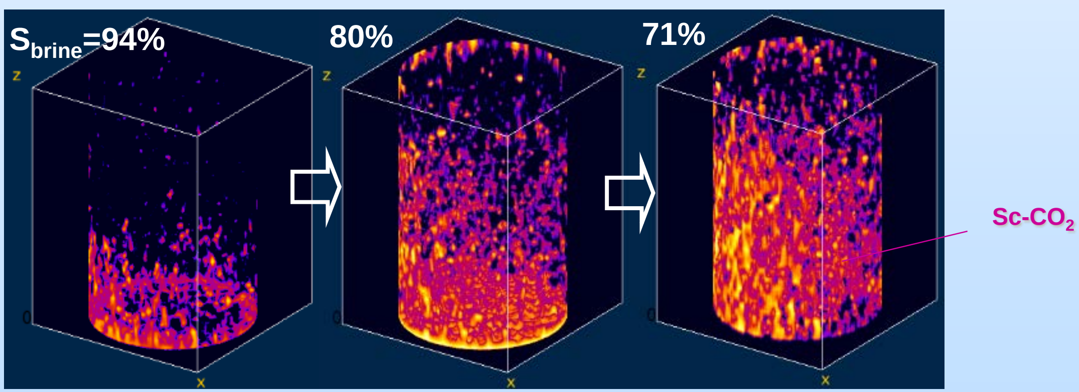
CO_2 Impact on Seismic Properties – LBNL's Split Hopkinson Resonant Bar Apparatus

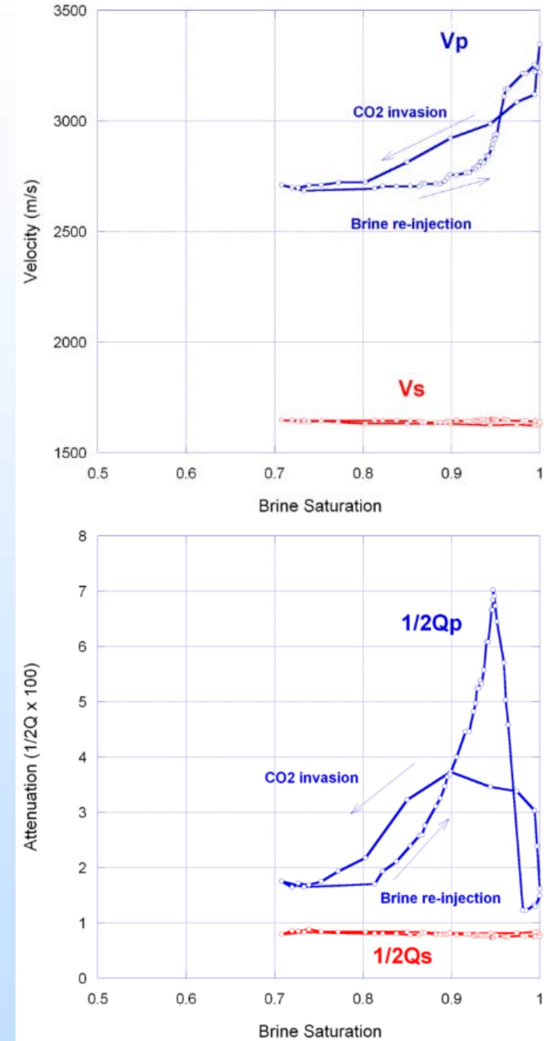
Resonant Bar Inner Chamber and housing

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



X-ray images of CO_2 core flood

Courtesy S. Nakagawa and T. Kneafsey, LBNL



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

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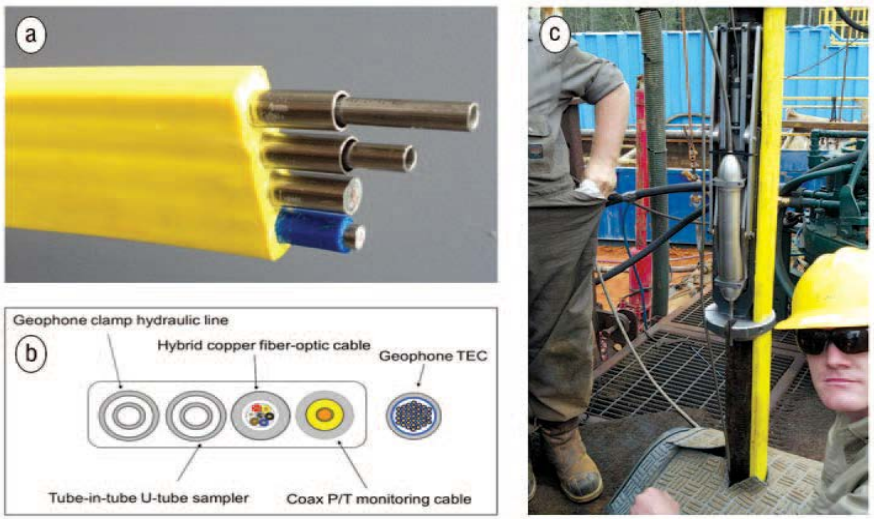
BSCSP Baseline, Operational & Post – Injection Monitoring

Near Surface			Deep Subsurface	
Atmosphere/ Remote	Soil	Surface & Shallow Waters	Above Injection Zone	Injection Zone
Differential Absorption LIDAR Hyperspectral Imaging Eddy Covariance	Soil Gas Composition CO_2 Soil Flux Wide Surveys CO_2 Soil Flux Fixed Chambers	Compliance Fluid Geochemistry Rare Earth Element Geochemistry	Distributed Pressure Distributed Temperature Pulsed Neutron Logs Dedicated USDW Well X-Well, VSP & Surface Seismic	X-Well, VSP & 3D-9C Surface Seismic Downhole P&T Pulsed Neutron Logs Geochemistry inc. Tracers, REEs

BSCSP Monitoring Program

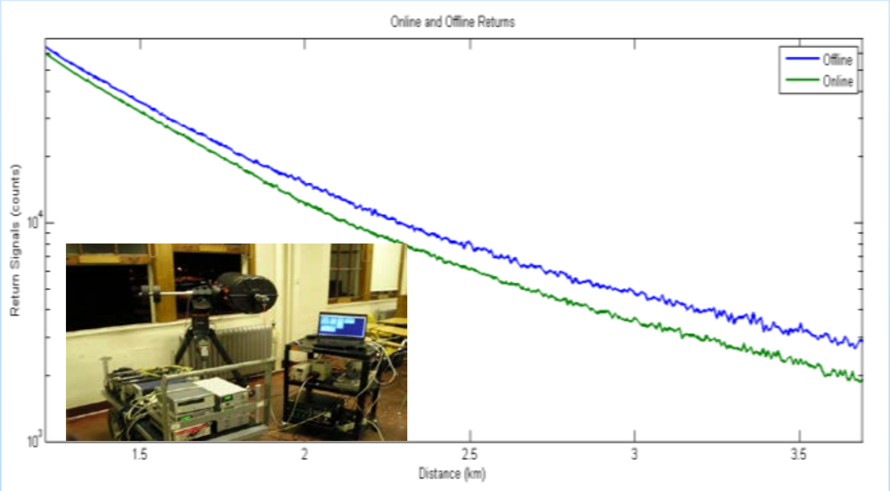


Integrated well instrumentation developed by LBNL capable of including DTS/DAS, u-tube fluid sampling, P/T, & geophysical cabling

UAV capable hyperspectral imaging system developed and tested by MSU and Resonon

In addition to standard geochemical fluid analysis, we will use introduced phase partitioning tracers and Rare Earth Elements as a natural tracer. REEs are detectable at the parts per trillion level and 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)

Field – rugged, pulsed Differential Absorption LIDAR developed by MSU with scanning and ranging capabilities and a 3.5 km radius



Geochemical Monitoring

Fluid Sampling

- Monthly Via U-tube in all monitoring wells until

Tracers

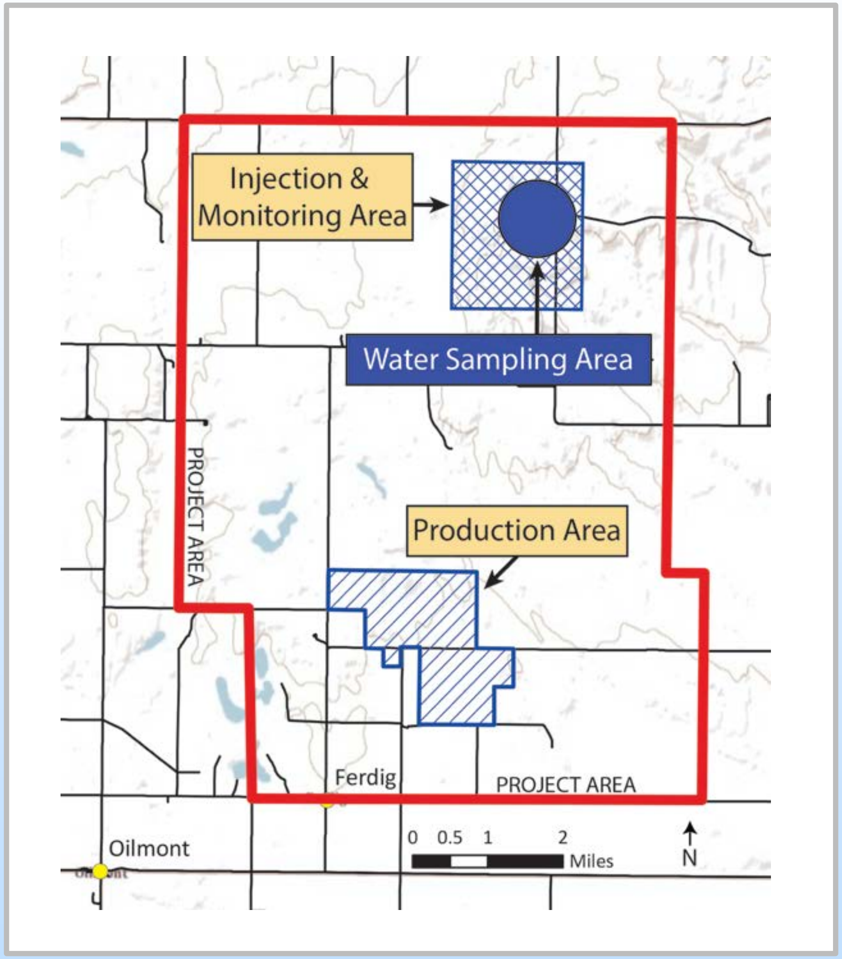
- Phase partitioning tracers
- SF_6
- $^{14}CO_2$
- Rare earth element

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

Core Testing & Analysis

- CO_2 flood and flow experiments
- Comparison of cores from gas cap with cores from injection zone pre- and post- injection

Assurance Monitoring - Establishing a Baseline Before CO_2 Injection



- Water chemistry
- Water quality
- CO_2 soil flux
- Imaging of vegetation
- Atmospheric CO_2

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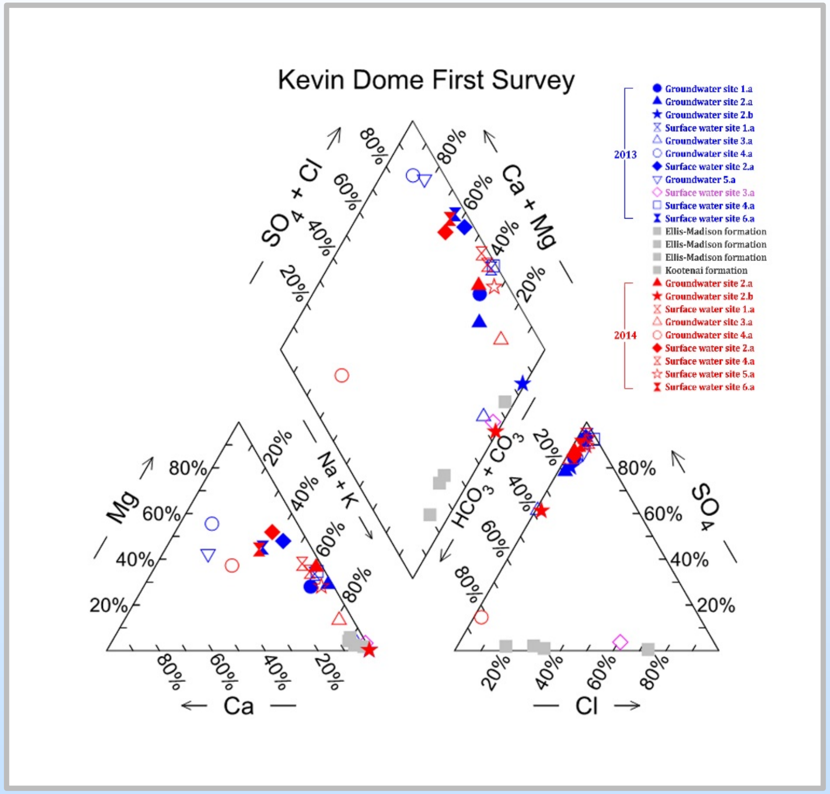
SAMPLING OF SHALLOW WELLS AND SURFACE WATERS

Samples collected Oct. 2013 and May 2014 from 6 wells and 6 surface waters in a 1.5 mile radius of the proposed injection well site.

General Water Chemistry



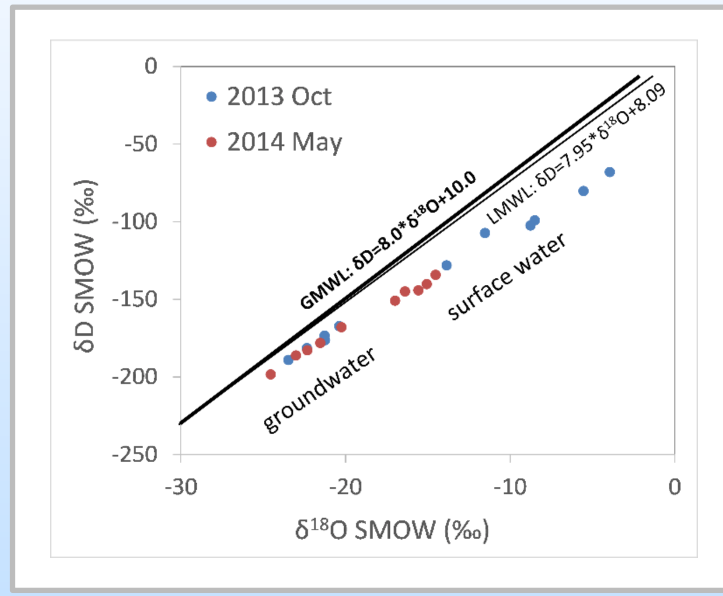
Idaho National Laboratory

- Most common ions are sodium (Na), sulfate (SO_4), and chloride (Cl)
- Chemically consistent with geology of the area
- Significant seasonal variability

Tracers

Establish a baseline for introduced (SF_6, SF_5CF_5, PFC's, ^{14}C) and natural (noble gases, H and O isotopes, ^{13}C) tracers.
RESULTS: Very low levels of SF_6, SF_5CF_3, PFC's measured (mostly below the detection limit)

H and O Isotopic Data



Lamont-Doherty Earth Observatory

δ^2H and $\delta^{18}O$ values are slightly below the global meteoric water line (GMWL) and the local meteoric water line (LMWL)

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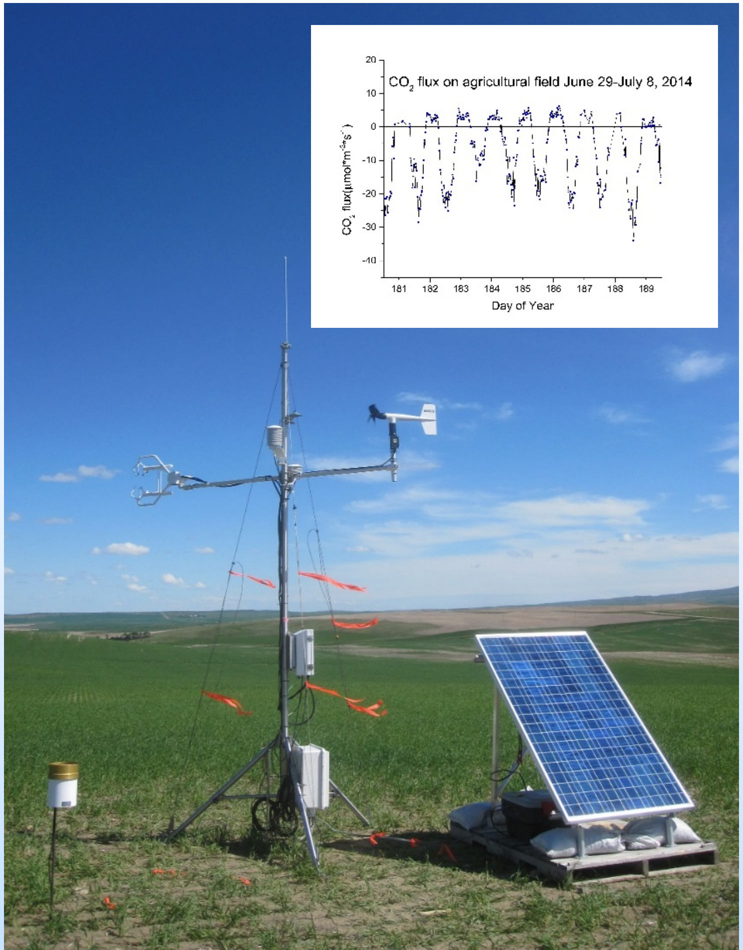
EDDY COVARIANCE



MSU

- Installed June 2014
- Data so far consistent with field in agricultural use

SOIL CO_2 FLUX SURVEY

MSU

- Portable accumulation chamber
- Survey done June 26-28, 2014
- 102-point grid covering 1 square mile centered on proposed injection site
- Values typical of soil under this type of land use

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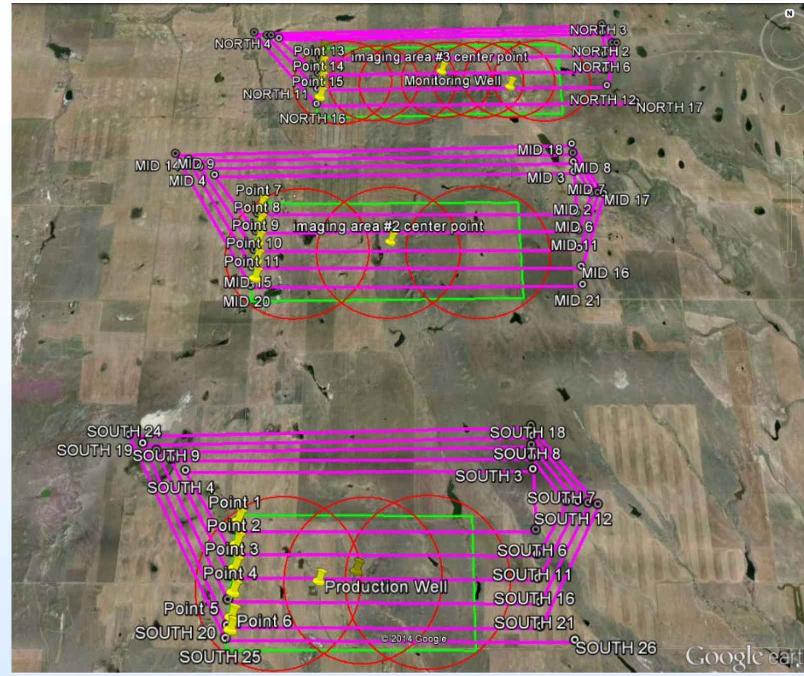
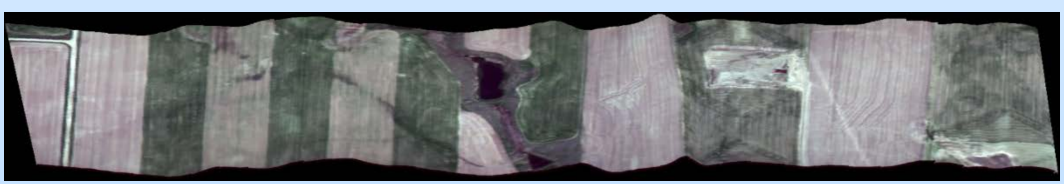
HYPERSPECTRAL IMAGING

The hyperspectral imaging system mounted in a Cessna 172 for flight based monitoring. Spectral reflectance between 400 and 1100 nm for each pixel of a digital image is collected.



The flight plan for monitoring the production well area, pipeline area, and injection well area.



Three color images of two flight paths on June 24, 2014. Initial geo-rectification using the Inertial Measurement Unit was conducted and further improvements to the geo-rectification will utilize ground based GPS data.

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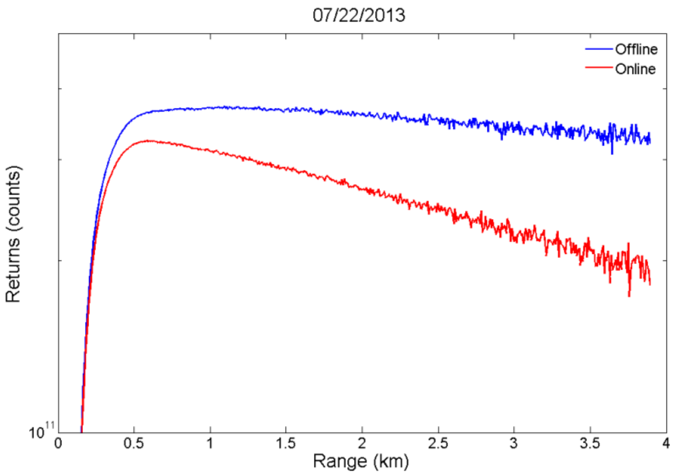
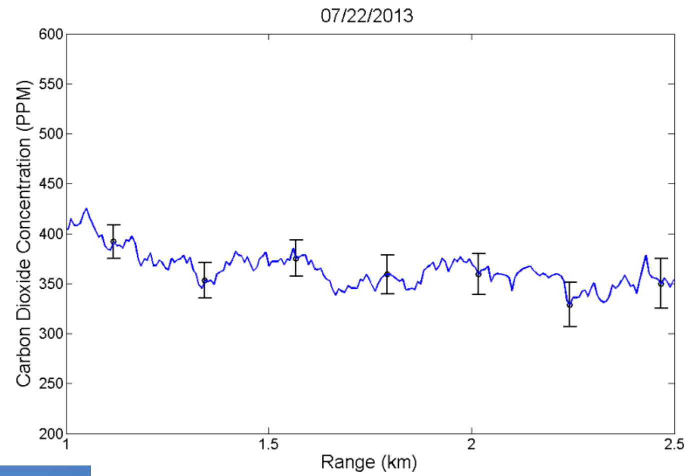
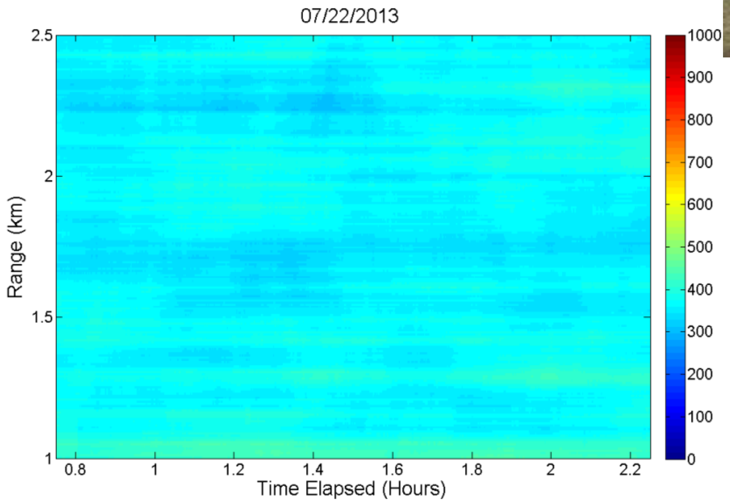
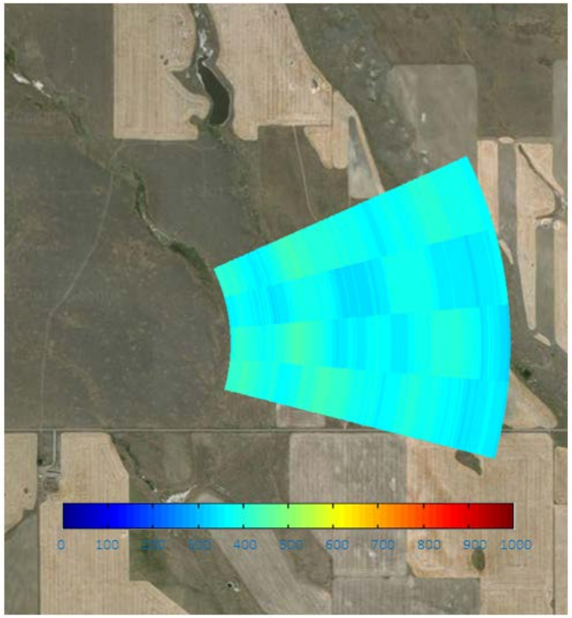
LIDAR (TESTED IN 2013 IN PRODUCTION AREA)



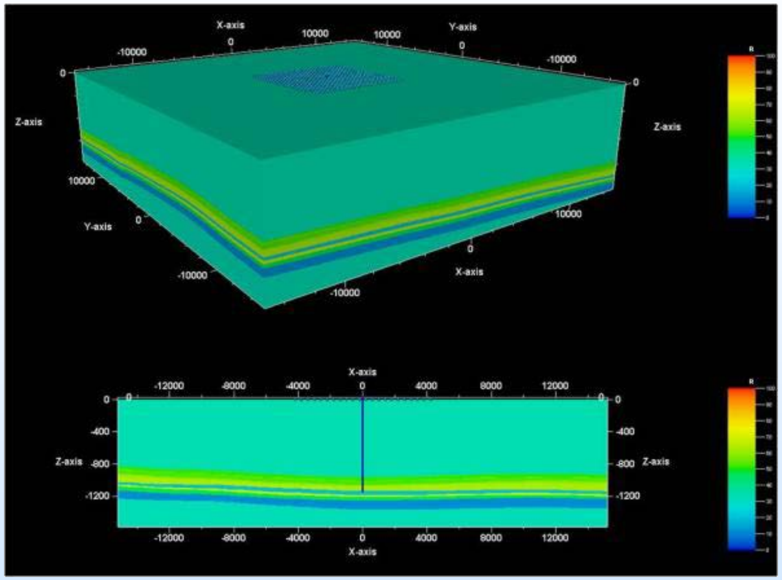




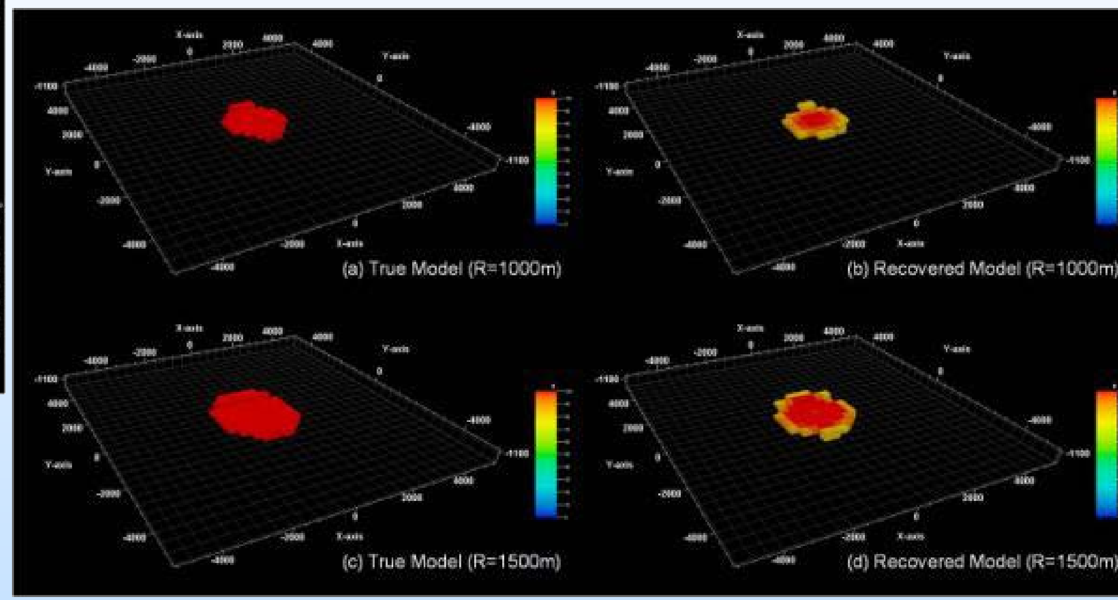


Borehole-to-Surface EM Feasibility Study

Michael S. Zhdanov, Masashi Endo and Noel Black, TechnoImaging;*
Andrew Hibbs and George A. Eiskamp, GroundMetrics;



3D resistivity model of the Kevin Dome. bipoles, one electrode for both transmitters is located on the surface



3D perspective view of the true model of CO_2 plume and the image recovered from 3D inversion of BSEM data (R = 1000 and 1500 m).

GROUNDMETRICS
TECHNOIMAGING
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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 25 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, being analyzed
  - Logs acquired
  - Seismic being tied to wells
- Baseline assurance monitoring initiated
  - Three water sampling campaigns
  - Soil flux (chambers, eddy covariance)
  - Hyperspectral Imaging flight
  - LIDAR

Summary

Site Characterization

- Strong evidence that the middle Duperow porosity zone is present over the dome
- Excellent log correlation between wells separated by 6 miles and data is consistent with 40 mi. cross-section
- Visual inspection of core indicates good porosity
- Some fractures in reservoir - likely to improve permeability
- Excellent S/N on p-wave seismic
- Very good S/N on shear wave data, even at long offset
  - This may permit separation of density & rigidity contributions to seismic response and CO_2 alteration of that response

Summary
(cont.)

Lack of infrastructure & weather conditions will present challenges

- Use of local oil operators should help

Outreach

- Communication and understanding individual landowner concerns is key
- A local (raised in community) site manager / project liaison is crucial in a rural setting

Permitting

- A large number of cultural resources exist in the area
- Local site manager should accompany permit agents

Questions

Lee Spangler

spangler@montana.edu

Requested Information

- DOE CCS Program Goals & Objectives
- Org Chart, Gantt Chart & Schedule
- Bibliography
- Supplemental Information

Carbon Storage Program Goals

(Benefit to the Program)

- **Support industries' ability to predict CO2 storage capacity in geologic formations to within ±30%**
  - The project will correlate logs, core studies, seismic and modeling efforts with multiple iterations through all stages of the project to determine actual storage compared to predicted. The project also tests storage in a regionally significant formation and in regionally significant structural closures that should refine regional capacity estimates.

- **Develop and validate technologies to ensure 99 percent storage permanence.**
  - The project will use 3D, 9C surface seismic, VSP, in zone and above zone geochemical sampling, repeat pulsed neutron logging, tracers, distributed T and P sensors and assurance monitoring techniques to verify location that the CO_2 remains in the storage complex.

Carbon Storage Program Goals

(Benefit to the Program) continued

- **Develop technologies to improve reservoir storage efficiency while ensuring containment effectiveness.**
  - Pulsed neutron logging and heat pulses to the reservoir combined with distributed temperature sensing should provide saturation information which can be studied as a function of injection rate. We will also measure rock physics properties as a function of CO_2 saturation to try to improve understanding of seismic response to S_{CO2}.

- **Develop Best Practice Manuals for monitoring, verification, accounting, and assessment; site screening, selection and initial characterization; public outreach; well management activities; and risk analysis and simulation.**
  - BSCSP will use information from this project to contribute to best practices manuals.

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Project Overview:
Goals and Objectives

Primary objective - Demonstrate that the target formation and other analogous formations are a viable and safe target for sequestration of a large fraction of the region's CO_2 emissions.

Success Criteria – Project safely injects CO_2 into the storage formation and models and monitoring indicate permanence of storage in the reservoir.

Other objectives include improving the understanding of injectivity, capacity, and storativity in a regionally significant formation.

Success Criteria – Site characterization, laboratory core studies, well tests, models coupled with operational data deepen understanding of use of site characterization data for predicting geologic system performance. Comparison of natural analog data with laboratory studies and geochemical sampling in the injection region improve understanding of injected CO_2 behavior in reactive rock.

Project Overview:
Goals and Objectives

Operational objectives - Safely procure, transport, inject and monitor up to one million tons of CO_2 into the target formation; understand the behavior of the injected CO_2 within the formation; verify and improve predictive models of CO_2 behavior; test and validate monitoring, verification and accounting (MVA) methodology.

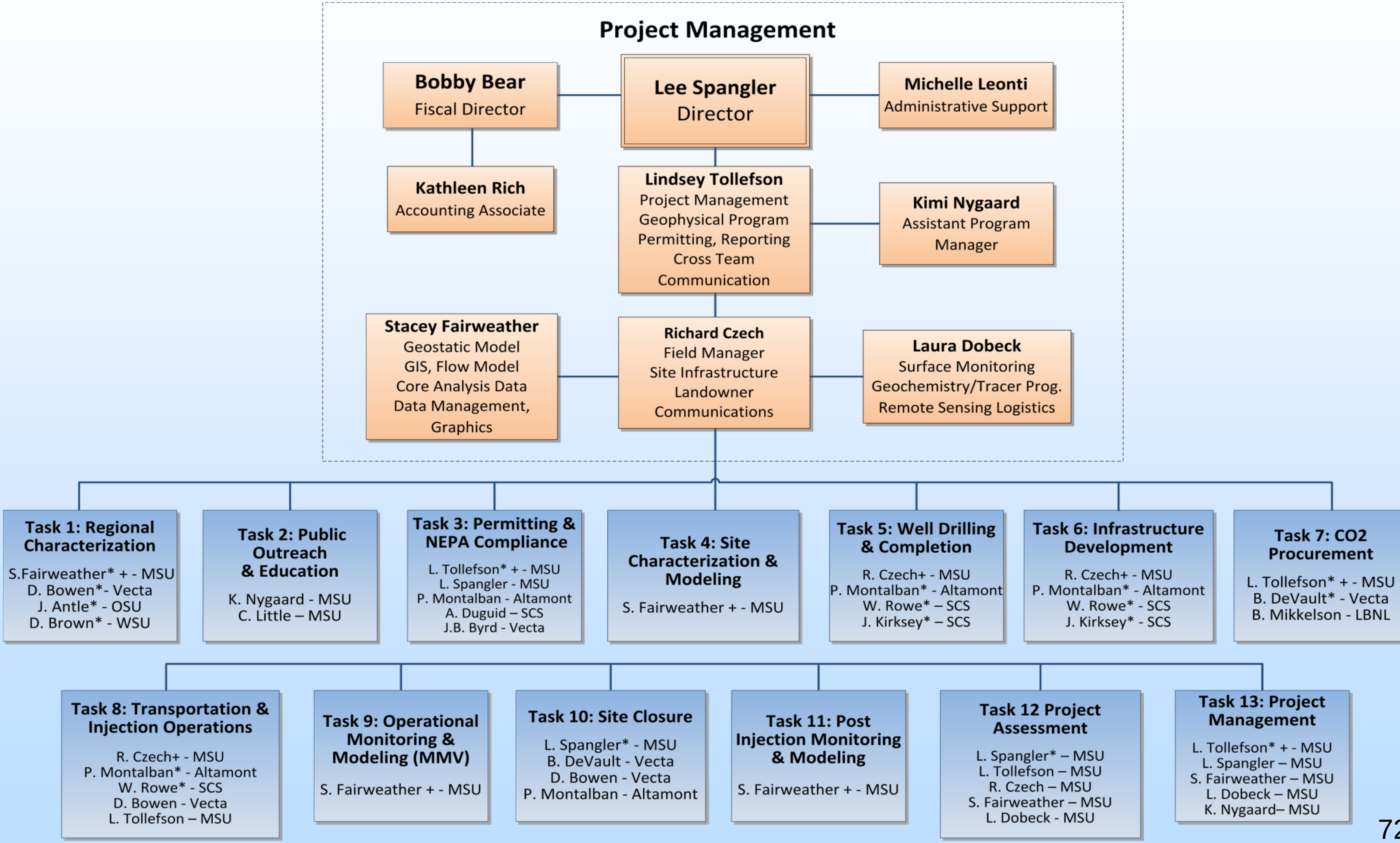
Success Criteria – Safe and successful injection; good history matching of multi-phase flow and reactive transport models; monitoring techniques detect CO_2 when present and provide information of plume development.

Post-injection phase objective - Assess any resultant changes from the CO_2 injection and to continue to monitor the CO_2 plume.

Success Criteria – Continued detection of plume evolution and models showing predictive capability.

Regional characterization objectives - Understand the costs of carbon sequestration; determine the best management practices to sequester carbon in the soil of agricultural systems; and refine regional assessments of CO_2 sources and capacity estimates.

Appendix
Organization Chart: Management

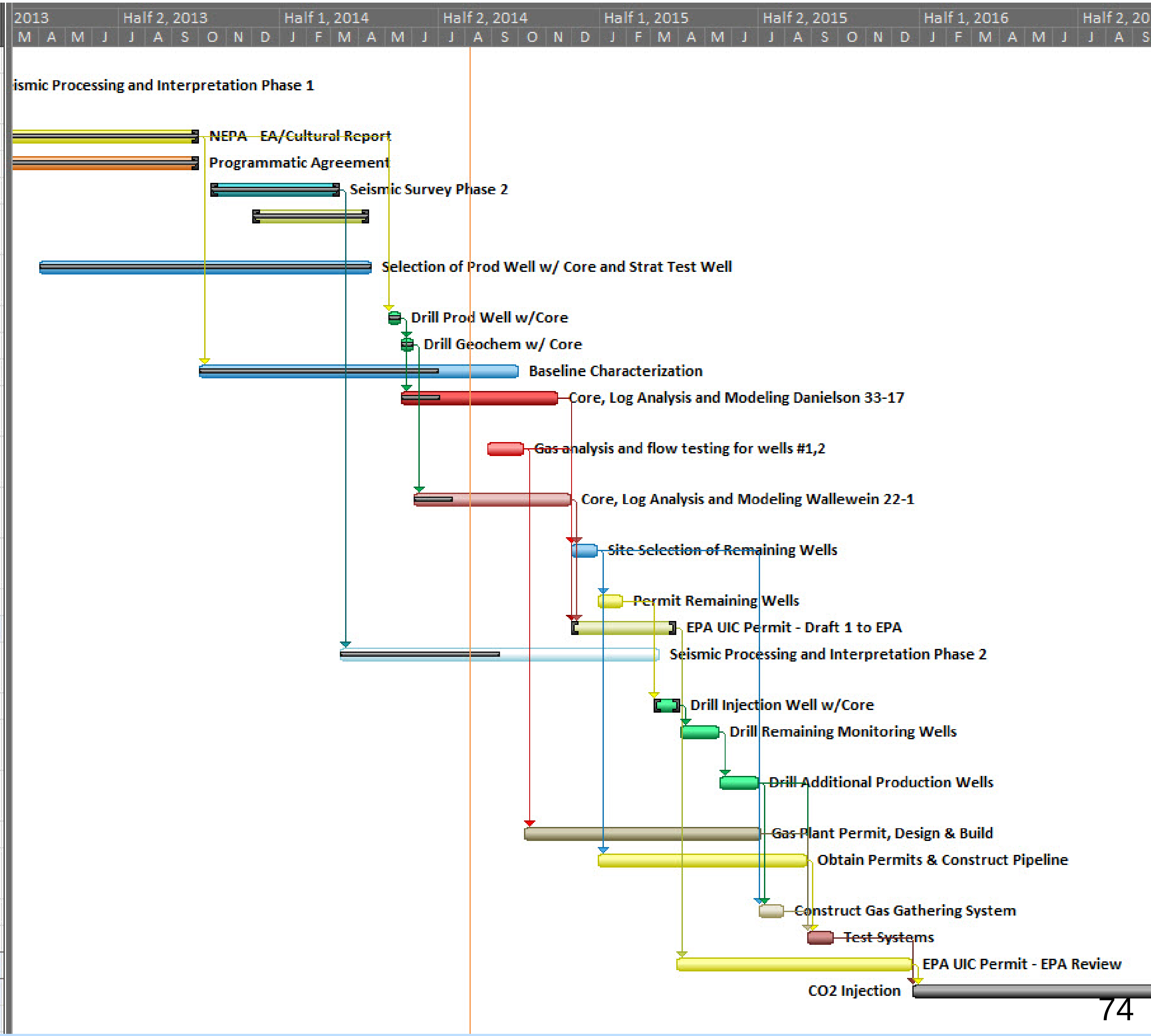


Appendix
Organization Chart: Project Partners

PARTNER	ROLE
Vecta Oil & Gas, Ltd.	• Characterization studies and site planning • Seismic profiling and surveying
Schlumberger	• Core extraction and rock sampling • Field operations and well drilling • Geophysical modeling and petrophysical analysis • Risk analysis and modeling
Columbia University & Barnard College	• Tracer studies • Carbon isotope analysis • Downhole monitoring
Altamont	• Well drilling and site planning • Infrastructure development • NEPA compliance and permitting
Idaho National Laboratory (INL)	• Tracer and mineralization studies (Rare Earth Elements) • Hydrogeologic modeling
Los Alamos National Laboratory (LANL)	• Core flood experiments • Secondary flow modeling • Risk analysis and modeling (CO2-PENS system model)
Lawrence Berkeley National Laboratory (LBNL)	• Seismic analysis on core properties • Primary flow modeling (U-Tube sampling)
Oregon State University	• Economic analysis and characterization studies

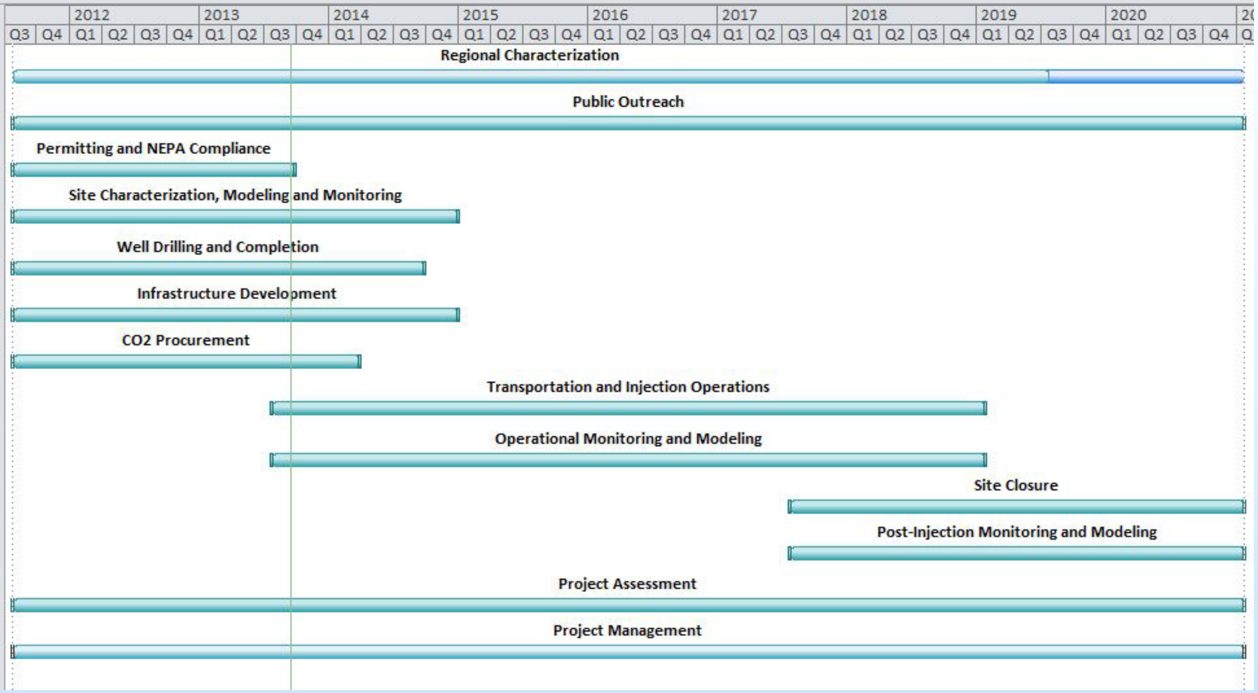
Appendix
Gantt Chart – Critical Path

Task Name	Start	Finish
Seismic Survey Phase 1	Mon 2/28/11	Mon 2/28/11
Seismic Processing and Interpretation Phase 1	Sun 4/1/12	Thu 1/31/13
NEPA - EA/Cultural Report	Mon 8/1/11	Mon 9/30/13
Programmatic Agreement	Sat 9/1/12	Mon 9/30/13
Seismic Survey Phase 2	Mon 10/14/13	Mon 3/10/14
Site Survey and Title Work for Strat Test Well	Sun 12/1/13	Sat 4/12/14
Selection of Prod Well w/ Core and Strat Test Well	Mon 4/1/13	Mon 4/14/14
Drill Prod Well w/Core	Mon 5/5/14	Sun 5/18/14
Drill Geochem w/ Core	Mon 5/19/14	Sun 6/1/14
Baseline Characterization	Tue 10/1/13	Tue 9/30/14
Core, Log Analysis and Modeling Danielson 33-17	Mon 5/19/14	Fri 11/14/14
Gas analysis and flow testing for wells #1,2	Tue 8/26/14	Mon 10/6/14
Core, Log Analysis and Modeling Wallewein 22-1	Mon 6/2/14	Fri 11/28/14
Site Selection of Remaining Wells	Sat 11/29/14	Sun 12/28/14
Permit Remaining Wells	Mon 12/29/14	Tue 1/27/15
EPA UIC Permit - Draft 1 to EPA	Sat 11/29/14	Sat 3/28/15
Seismic Processing and Interpretation Phase 2	Tue 3/11/14	Tue 3/10/15
Drill Injection Well w/Core	Tue 3/3/15	Wed 4/1/15
Drill Remaining Monitoring Wells	Thu 4/2/15	Sat 5/16/15
Drill Additional Production Wells	Sun 5/17/15	Tue 6/30/15
Gas Plant Permit, Design & Build	Tue 10/7/14	Fri 7/3/15
Obtain Permits & Construct Pipeline	Mon 12/29/14	Tue 8/25/15
Construct Gas Gathering System	Wed 7/1/15	Thu 7/30/15
Test Systems	Wed 8/26/15	Thu 9/24/15
EPA UIC Permit - EPA Review	Sun 3/29/15	Wed 12/23/15
CO2 Injection	Thu 12/24/15	Fri 11/2/18
Post Injection Work	Sat 11/3/18	Tue 4/7/20



Appendix
Gantt Chart – by Task

Task #	Task Name	Start	Finish
1.0	Regional Characterization	Mon 7/25/11	Mon 1/25/21
2.0	Public Outreach	Sun 7/24/11	Mon 1/25/21
3.0	Permitting and NEPA Compliance	Mon 7/25/11	Mon 9/30/13
4.0	Site Characterization, Modeling and Monitoring	Mon 7/25/11	Wed 12/31/14
5.0	Well Drilling and Completion	Mon 7/25/11	Tue 9/30/14
6.0	Infrastructure Development	Mon 7/25/11	Wed 12/31/14
7.0	CO2 Procurement	Mon 7/25/11	Sun 3/30/14
8.0	Transportation and Injection Operations	Thu 7/25/13	Thu 1/24/19
9.0	Operational Monitoring and Modeling	Thu 7/25/13	Thu 1/24/19
10.0	Site Closure	Tue 7/25/17	Mon 1/25/21
11.0	Post-Injection Monitoring and Modeling	Tue 7/25/17	Mon 1/25/21
12.0	Project Assessment	Mon 7/25/11	Mon 1/25/21
13.0	Project Management	Mon 7/25/11	Mon 1/25/21



Appendix
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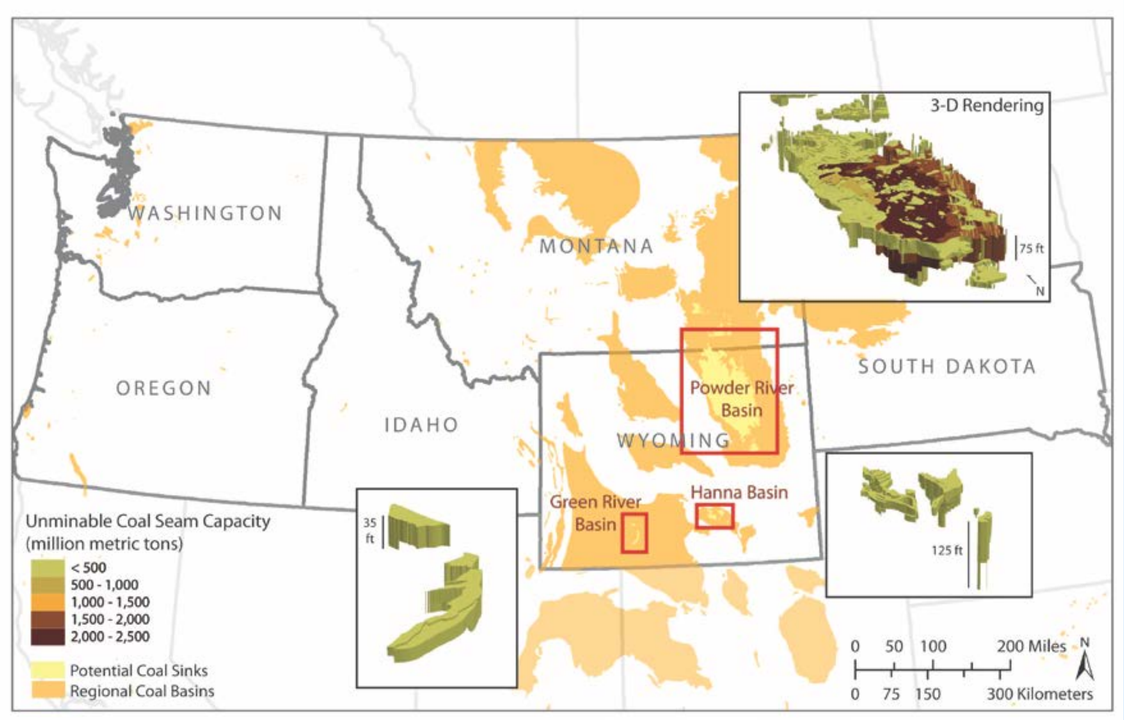
Appendix: Supplemental Material

Task 1 - Regional Characterization / GIS



- Geospatial analysis and data management to support project scientists
- Visualization and interpretation of geospatial data for public outreach applications (interactive mapping tools, static maps, and graphics)
- Expansion of the current database to aid development of commercial scale projects across the region and contribute to the national CCS perspective.

BIG SKY CARBON SEQUESTRATION PARTNERSHIP

MONTANA STATE UNIVERSITY