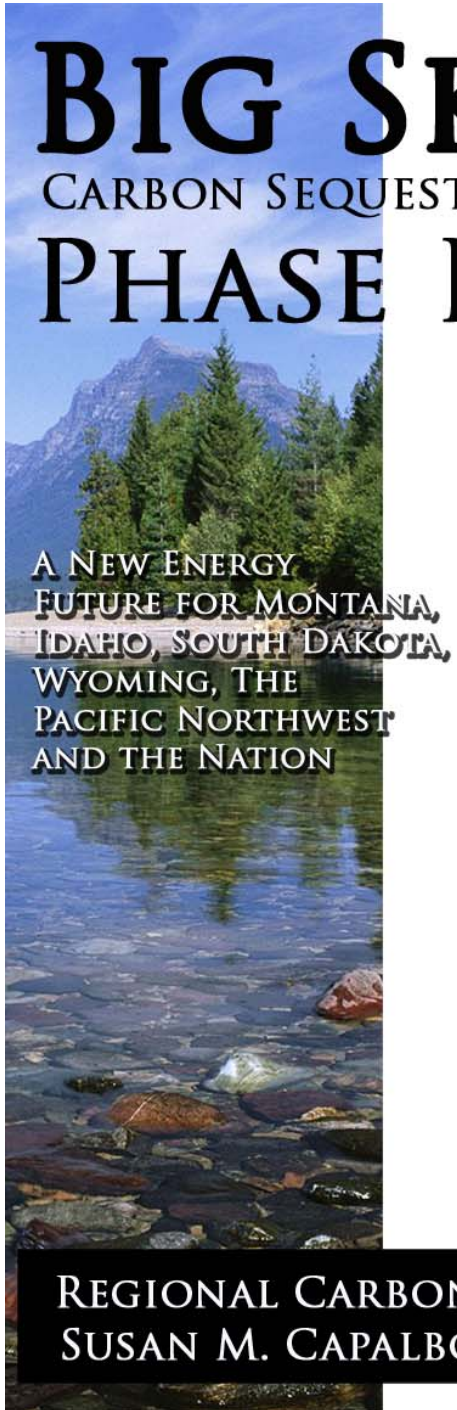


Phase II Overview

Presentation by

Susan Capalbo
Bob Smith
Dave Brown

Composition of Partnership

- Research Institutions (universities, labs, others)
- State, federal agencies (includes USDA, USGS, NASA)
- Industry members including major power producers (Energy Northwest, Sempra Generation, Portland General Electric, Puget Sound Energy)
- Carbon trading entities (NCOC)
- Outreach Education partners
- Tribal Nations and Councils
- International Collaborators

International partners

FRANCE:	Institut de Physique du Globe de Paris
INDIA:	National Geophysical Research Institute
RUSSIA:	Vernadsky Institute of Geochemistry and Analytical Chemistry of the Russian Academy of Sciences
CANADA:	BioCap Canada
	Semiarid Prairie Agricultural Research Centre
NETHERLANDS:	Wageningen Universiteit, Lab of Soil Science and Geology
NORWAY:	Det Kongelige Olge - Og Energidepartement
	Institute for Energy Technology
	Norwegian University of Science & Technology
	Research Council of Norway, Hanshaugen
	SINTEF Petroleum Research

Framework for Phase II

13 Tasks covering

geological pilots

terrestrial pilots

integration efforts:

- **GIS,**
- **Outreach**
- **Economic analysis**

Framework continued

Geological Efforts

- **Two Field Pilots**
  - **Basalt/mafic rock (Columbia River Basalts)**
  - **Reactive carbonate reservoir (Madison formation)**
- **Enhanced CBM Design Study**
- **National Mafic Rock Atlas**

Terrestrial Efforts

- **Two Field pilots: Cropland and Forestry**
- **Rangeland design study**

Time Sensitive Activities

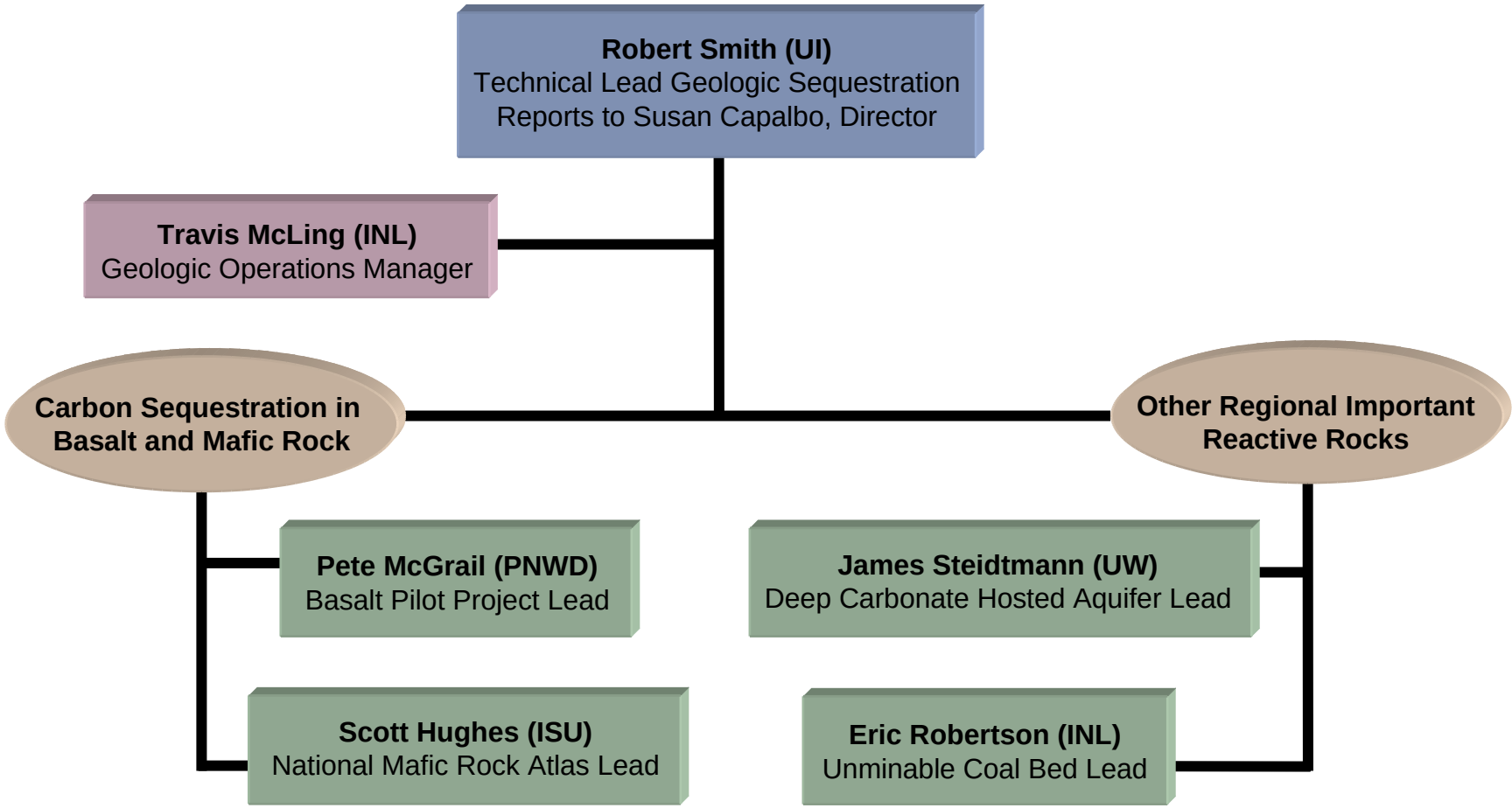
Mafic Rock Pilot

	Year 1	Year 2	Year 3	Year 4
Preinjection characterization and permitting				
Injection				
postinjection coring				

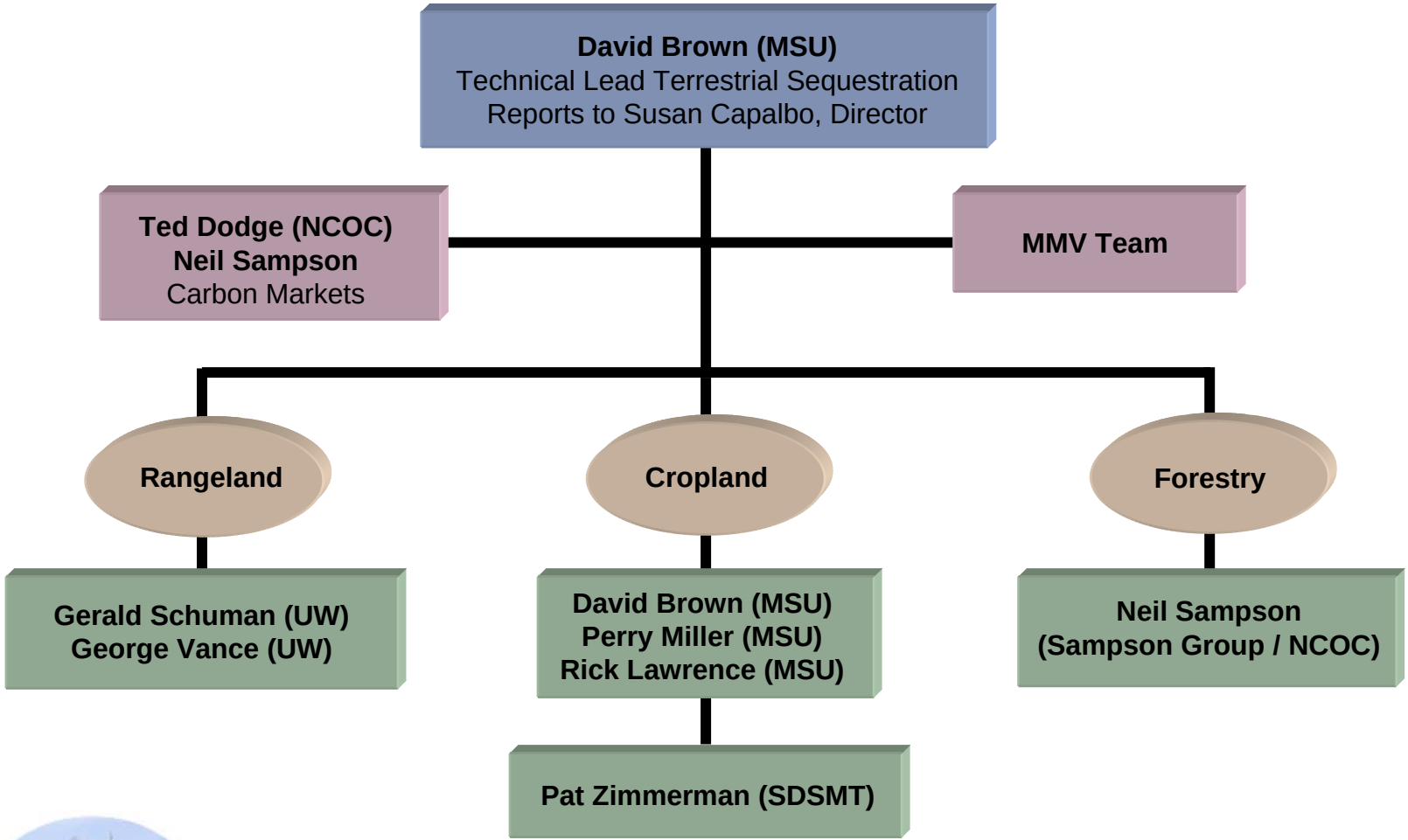
Terrestrial Pilots

	Year 1	Year 2	Year 3	Year 4
Cropland enrollment				
soil sampling/MMV				
Controlled cropland pilots				
soil sampling				
biomass sampling				
stable isotopes				
Forestry enrollment				
plot MMV				
Remote sensing MMV				

Geologic Team



Terrestrial Team



Integration Activities: GIS

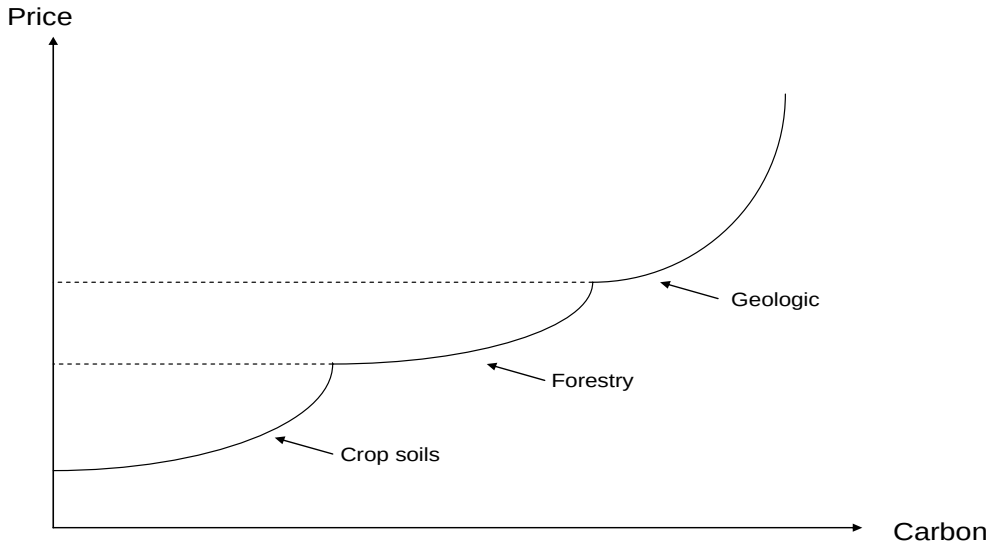
- Continue to develop **Big Sky Knowledge Base**
  - **Big Sky Carbon Atlas**: regional sources, terrestrial sinks, geologic sinks, base data; national mafic database
  - **Big Sky Data Library**: databases for mafic, carbonate, and terrestrial pilots, and for economic analysis
- Continue to develop **Big Sky Data Warehouse** for web-based access to data (via SDE and IMS)
- Participate in **GIS coordination** efforts (intra- and inter-partnership, NatCarb, DOE Geospatial Science Program, Geospatial One-Stop, etc.)
- Contribute to **education and outreach** efforts

Integration Activities: Carbon Market

- **Implement pilot forestry, agroforestry, and cropland carbon sequestration projects** in conjunction with landowners, and national and international carbon trading companies.
- All pilot projects will be marketed through **Nat Source via CCX** and/or other emerging markets.
- Two 12,500 ton portfolios (tribal & private landowners).
- Seating a **Technical Standards Committee** for the purpose of setting project standards for the portfolio projects.

Integration Activities: Economic Analysis

- Economic Potential for Geologic and Terrestrial Sequestration
- Quantify Regional Carbon Supply Curves
- Potential for Large Scale Deployment



Economic Potential -- Geologic

- Modeling framework for simulation analysis for major geologic options in the BS region
- Data to parameterize model from pilots, industry partners, scientists and the literature
  - capture, transport and processing CO2
  - drilling and pumping, methane recovery
  - management and MMV

Economic Potential -- Terrestrial

- Extend Phase I analysis of crop land soil sequestration to include grazing lands
- Adapt existing national model of forestry sequestration to Big Sky region

Why is this Important

- Critical to addressing the feasibility of scaling up of the sequestration activities
- Useful for addressing long term financial viability of power plants under carbon-constrained scenarios
- Used to address tradeoffs among alternative sequestration options

Integration Activities: Public Outreach & Education

- Build public acceptance and support
- Ensure field validation permitting requirements are met
- Pursue practical coalition building
- Highlight results

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TRAVIS MCLING - IDAHO NATIONAL LABORATORY (INL)
PETE MCGRAIL - BATTELLE PACIFIC NORTHWEST DIVISION (PNWD)

Public Outreach & Education: Approach

- Emphasize technology solutions and economic development opportunities
- Establish and leverage strategic networks (local - international, media)

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Public Outreach & Education: Activities

- Annual Energy Forum & Report
- Energy Future Coalition
- State Legislative Symposia
- Partnership Recognition/Media Network
- National Outreach Working Group
- Capacity Building

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Geological Sequestration

- Partnership emphasis is on major regional geologic structures that have potential for CO_2 emissions abatement from future coal-based power production
- Sequestration pilot projects focus on reservoirs that are chemically reactive with CO_2 in addition to normal hydrodynamic and solubility trapping
  - Basalt (Mafic Rock) Aquifer Pilot (mineralization)
  - Carbonate Petroleum Reservoir Pilot (alkalinity)
  - Enhanced Coal Bed Sequestration (sorption)

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Rationale for Basalts

- Major flood basalt formations exist throughout the world
  - Important role in global carbon cycle
  - Implicated in past climate change events
  - Not widely considered as a geological sequestration option
- Over 30 years and >$400M of prior DOE investment in understanding basalt/aquifer systems that can be applied to carbon storage
- Water Resource Implications
  - Upper aquifers (<300 m) are major source of water
  - Deeper aquifers contain non-potable water

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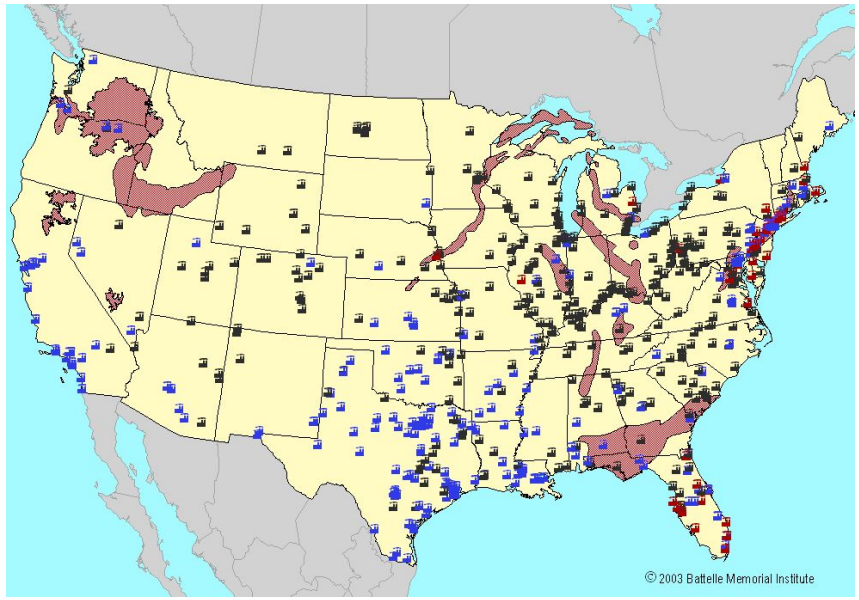
National Mafic Rock Atlas

- Develop a GIS-based tool that integrates
  - modeling studies
  - laboratory tests
  - pilot project insights
- Provides for transferablity of results nationally and internationally



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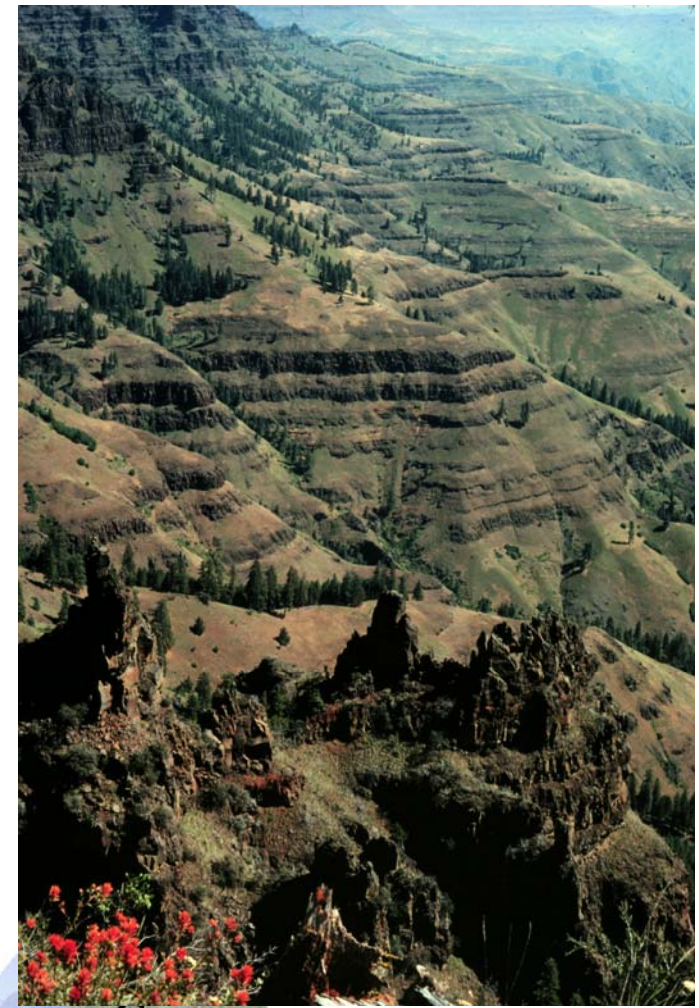
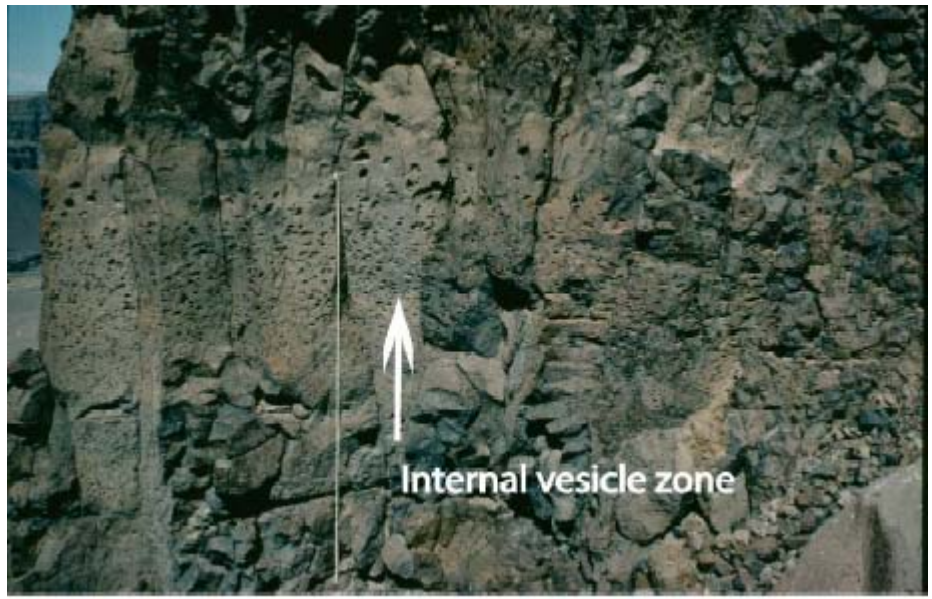
Layered Basalt Flows





- Assume only 10 flows (3%) suitable for injection, thickness of only 10 m, 15% porosity, 1400 psi average pressure
- ≈100 $GtCO_2$ storage capacity

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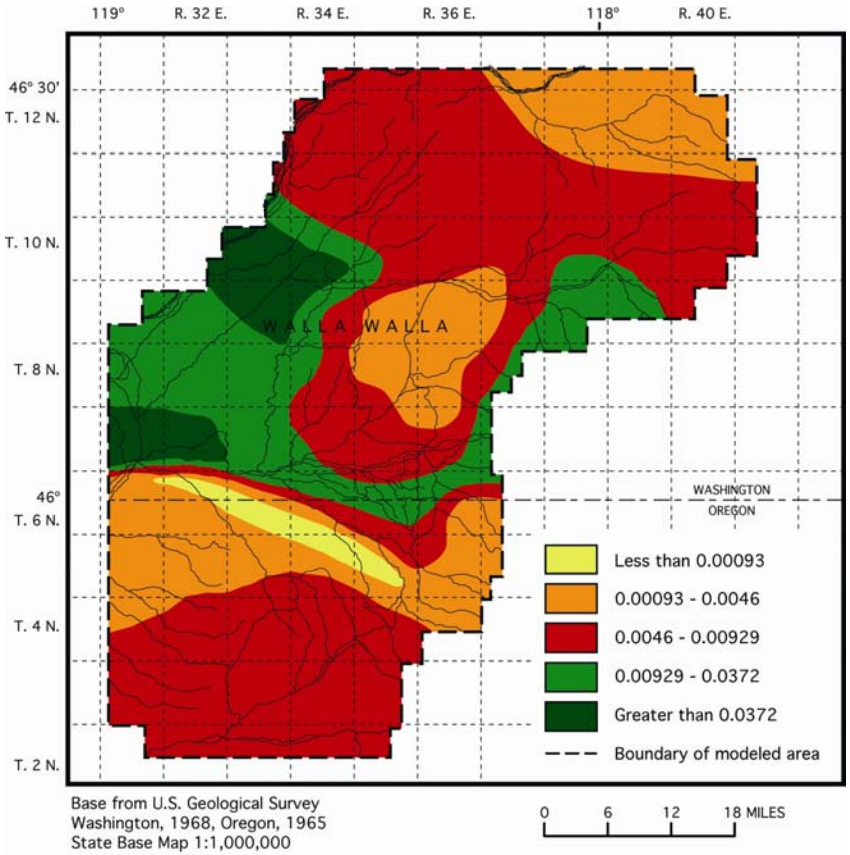
Transmissivity of Basalt Aquifer System

- Shallow basalts serve as regional aquifer systems
- Proven connectivity over multi-km scale of importance for geologic sequestration



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Generalized Mineralization Scheme

$$CO_2(g) \xrightleftharpoons{K_h} CO_2(aq)$$

$$\downarrow$$

$$CO_2(aq) + H_2O \xrightleftharpoons{K_1} HCO_3^- + H^+$$

$$\downarrow$$

$$(Ca,Mg,Fe)_xSi_yO_{x+2y} + 2xH^+ + (2y - x)H_2O \xrightarrow{k_2} x(Ca,Mg,Fe)^{2+} + yH_4SiO_4(aq)$$

$$\downarrow$$

$$(Ca,Mg,Fe)^{2+} + HCO_3^- \xrightleftharpoons{K_3} (Ca,Mg,Fe)CO_3 + H^+$$

Expected to be slow step in reaction but…

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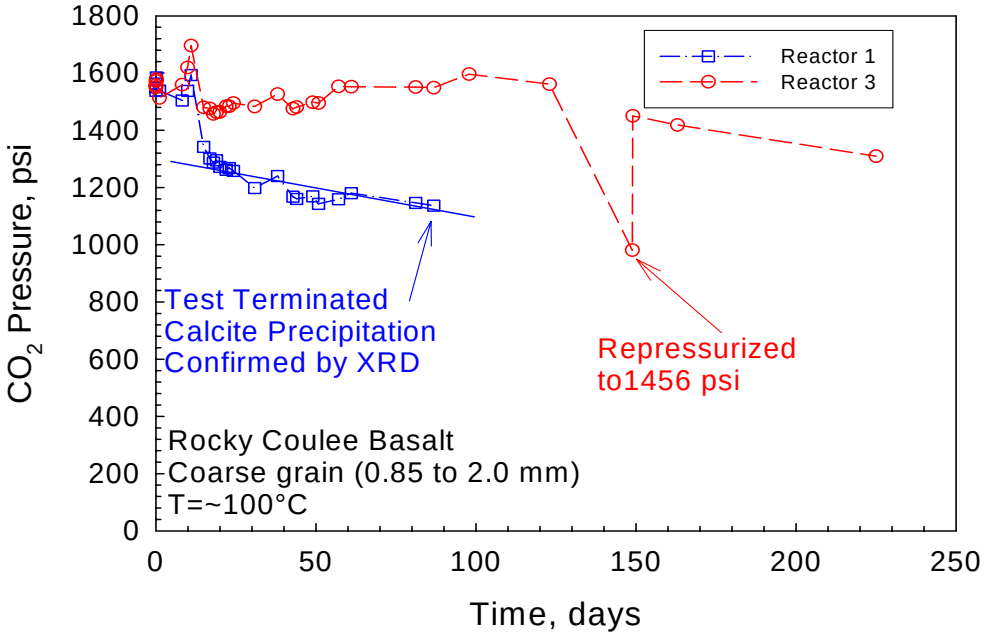
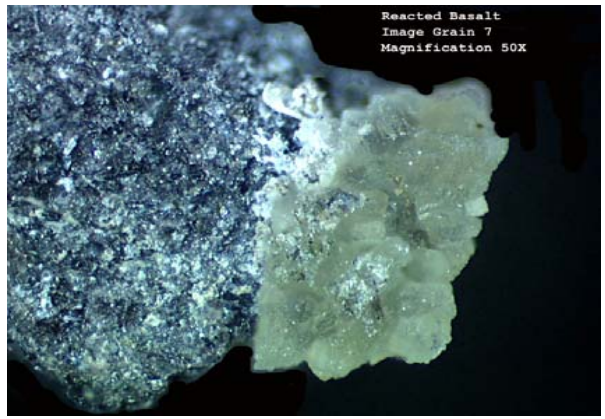
TRAVIS MCLING - IDAHO NATIONAL LABORATORY (INL)
PETE MCGRAIL - BATTELLE PACIFIC NORTHWEST DIVISION (PNWD)

Supercritical CO_2 Pressure Cell Experiments with Columbia River Basalt





Long-term experiments showing transition from calcite to ankerite, $Ca(Fe, Mg, Mn)(CO_3)_2$

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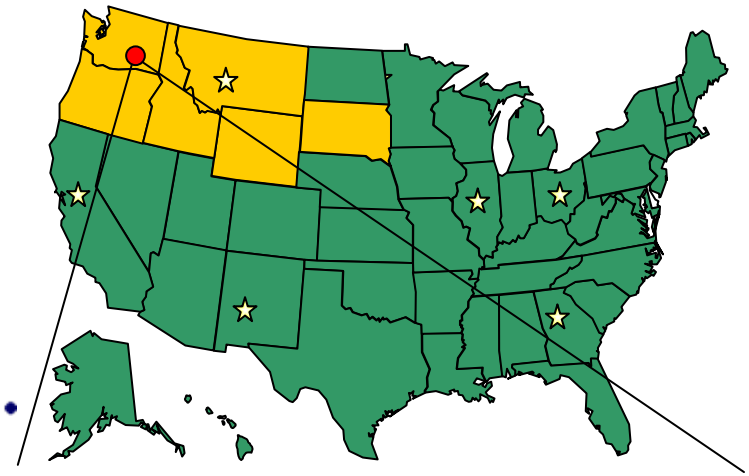
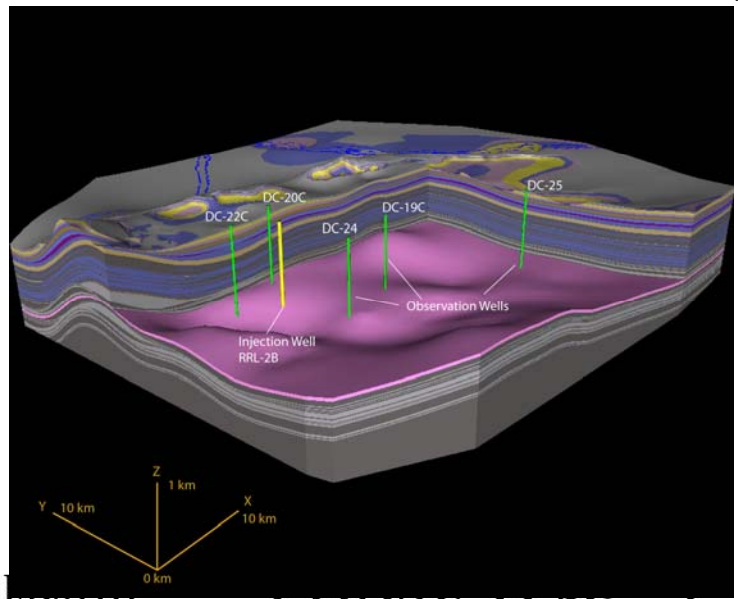
TRAVIS MCLING - IDAHO NATIONAL LABORATORY (INL)
PETE MCGRAIL - BATTELLE PACIFIC NORTHWEST DIVISION (PNWD)

Basalt Field Pilot

- 3000 MT of CO_2 transported by rail from refinery
- Utilize existing deep well infrastructure to minimize drilling costs for injection and monitoring
- Target is Grande Ronde basalt formation (1100 m depth)
- Post injection core sampling to verify mineralization reactions
- Validate supercomputer simulations of CO_2 dispersion, dissolution, and trapping in basalt using suite of geophysical, hydrologic, and tracer methods

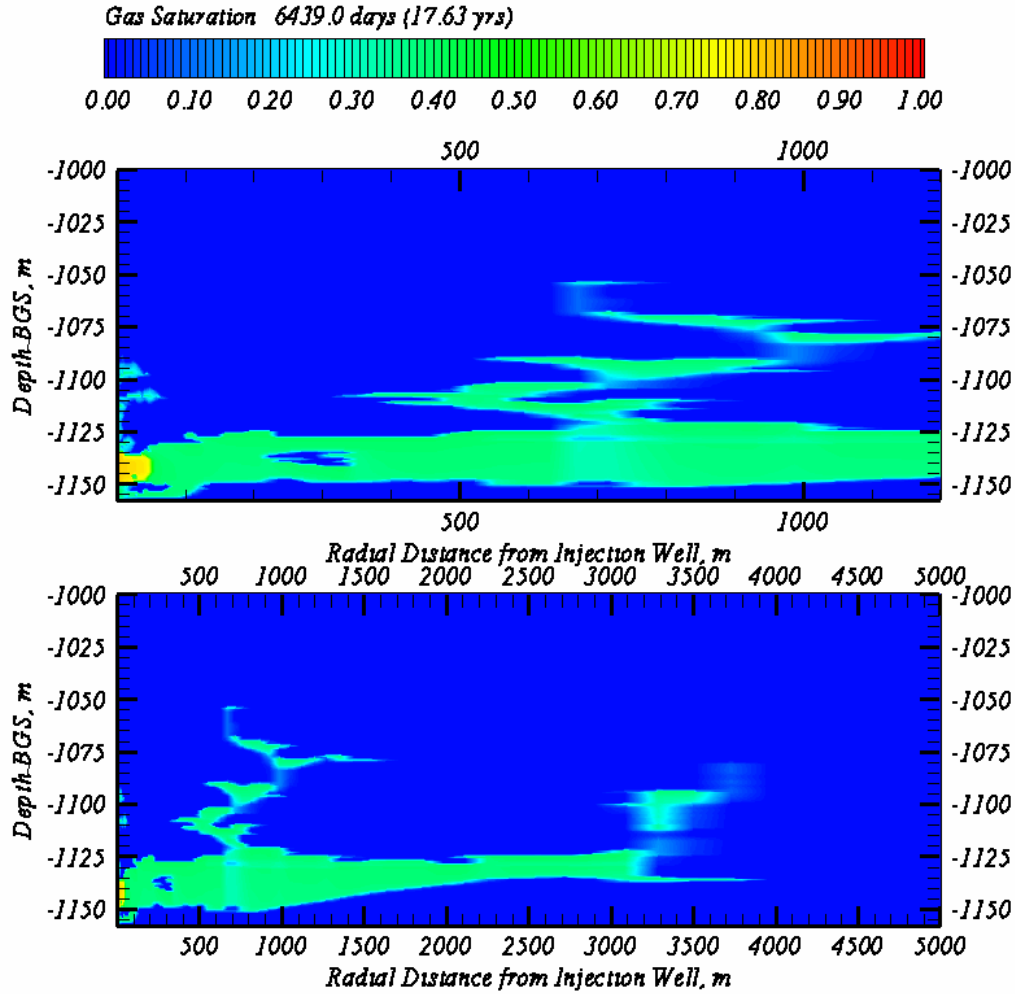




BIG SKY CARBON SEQUESTRATION PARTNERSHIP

ROBERT SMITH - UNIVERSITY OF IDAHO AT IDAHO FALLS
TRAVIS MCLING - IDAHO NATIONAL LABORATORY (INL)
PETE MCGRAIL - BATTELLE PACIFIC NORTHWEST DIVISION (PNWD)

Supercomputer Simulation of CO_2 Injection in Grande Ronde Basalt



BIG SKY CA

II Kick-off

Robert Smith - University of Idaho at Idaho Falls
Travis McLing - Idaho National Laboratory (INL)
Pete McGrail - Battelle Pacific Northwest Division (PNWD)

Push-Pull Mafic Rock Test

- Asses in situ basalt dissolution rates
- Inject CO_2 charged water into shallow existing wells
  - Less expensive than super critical CO_2 injections
  - Allows parameterization of reactive models for pilot project
  - Allows assessment of spatial variability
- Lamont Doherty

Mafic Pilot MMV

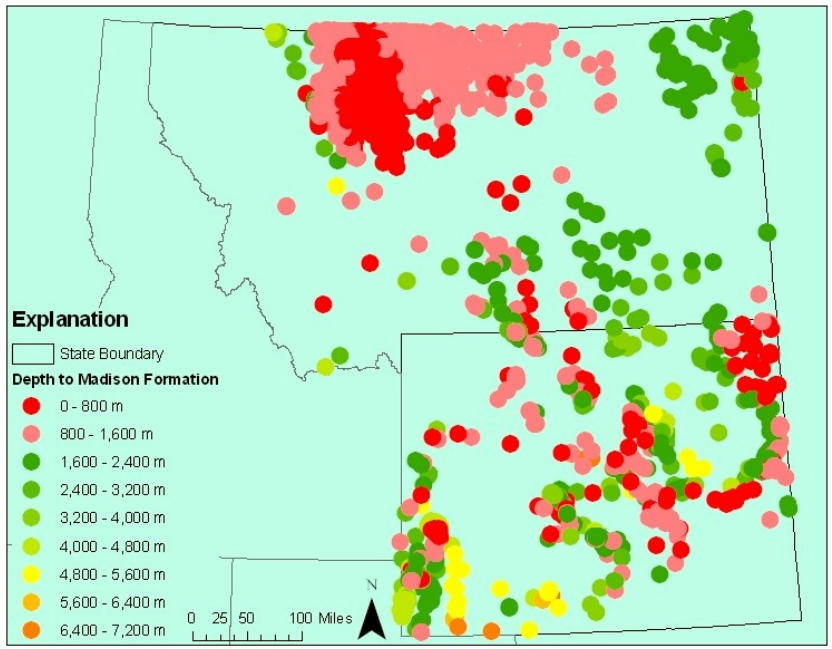
- Land Surface Monitoring (ES&H)
- Geophysics
  - Boise State University
  - Los Alamos National Laboratory
  - NGRI (India)
- Tracers
  - IDPG (France)
  - Vernadsky Institute (Russia)
- Post injection coring
  - Lamont Doherty

Carbonate Petroleum Reservoir Pilot

- Regionally abundant carbonate rocks (dolomites and limestones) are highly reactive with CO_2

  $$CaMg[CO_3]_2 + 2CO_2 + 2H_2O \rightarrow Ca^{2+} + Mg^{2+} + 4HCO_3^-$$

- Reactions should result in permeability and porosity increases



Depth to top of Madison Formation

ROBERT SMITH - UNIVERSITY OF IDAHO AT IDAHO FALLS
TRAVIS MCLING - IDAHO NATIONAL LABORATORY (INL)
PETE MCGRAIL - BATTELLE PACIFIC NORTHWEST DIVISION (PNWD)

Objective and Approach

- Assess long-term CO_2 mineralization rates in a carbonate host reservoir (Madison Formation target)
- Collect core from reservoir that has undergone CO_2 EOR
  - long CO_2 exposure history
  - Compare to preinjection core
  - Validate predictive modeling of CO_2 injection

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TRAVIS MCLING - IDAHO NATIONAL LABORATORY (INL)
PETE MCGRAIL - BATTELLE PACIFIC NORTHWEST DIVISION (PNWD)

Modeling of CO_2 inject history

- Focus on the consequences of the long-term exposure of carbonate rocks to CO_2-rich fluids
- Conduct modeling studies to match the history of preinjection and post injection conditions
  - Changes in water chemistry
  - Changes in permeability and porosity
  - Quantify changes in carbon storage potential

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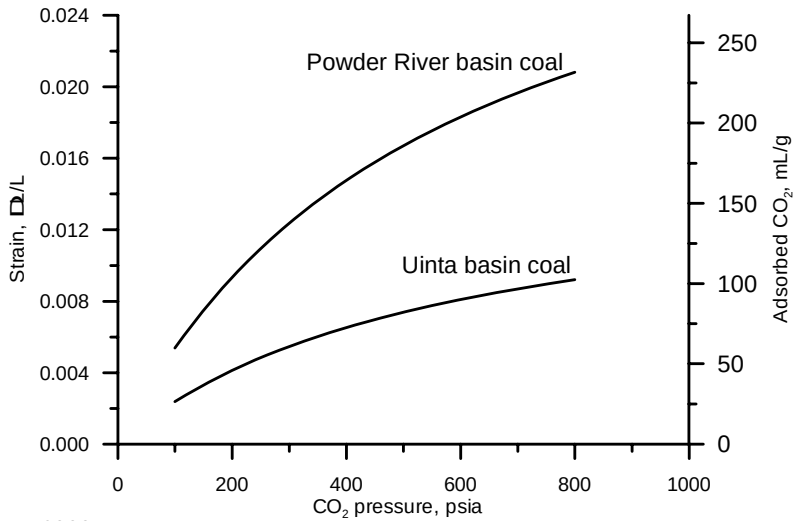
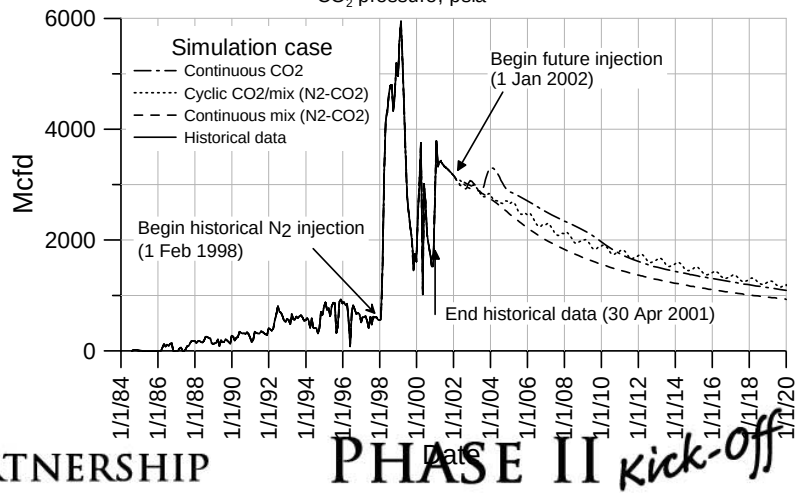
PETE MCGRAIL - BATTELLE PACIFIC NORTHWEST DIVISION (PNWD)

Enhanced Coal Bed Sequestration

- Recent work shows Powder River basin coals can adsorb twice as much CO_2 as Uinta basin coals
- Study various gas injection strategies
  - Economic evaluation
  - Reservoir simulation
- Attention will be given to impact of coal swelling on permeability changes





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TRAVIS MCLING - IDAHO NATIONAL LABORATORY (INL)
PETE MCGRAIL - BATTELLE PACIFIC NORTHWEST DIVISION (PNWD)

Terrestrial Pilots

David Brown
Montana State University

Terrestrial Pilot Projects

- **Forestry**
- **South Dakota web-based enrollment**
  - Private lands (Big Sky)
  - Tribal lands (Big Sky + national)
  - C-lock®, Century model
  - Year 4 remote sensing (MMV)
  - No-till cropland, CRP, rangeland
  - Monitor soil & biomass C in existing range management studies
  - Sampling costs and information gains from spatial-temporal sampling designs

Random plot

MMV

- **Wyoming Rangeland**
- **North Central Montana cropland**
  - Canada National Carbon and Greenhouse Gas Accounting and Verification System (NCGAVS)

South Dakota School of Mines and Technology

Institute of Atmospheric Sciences

Ted Dodge & Ne

Jerry Schuman & George Vance

National Carbon C

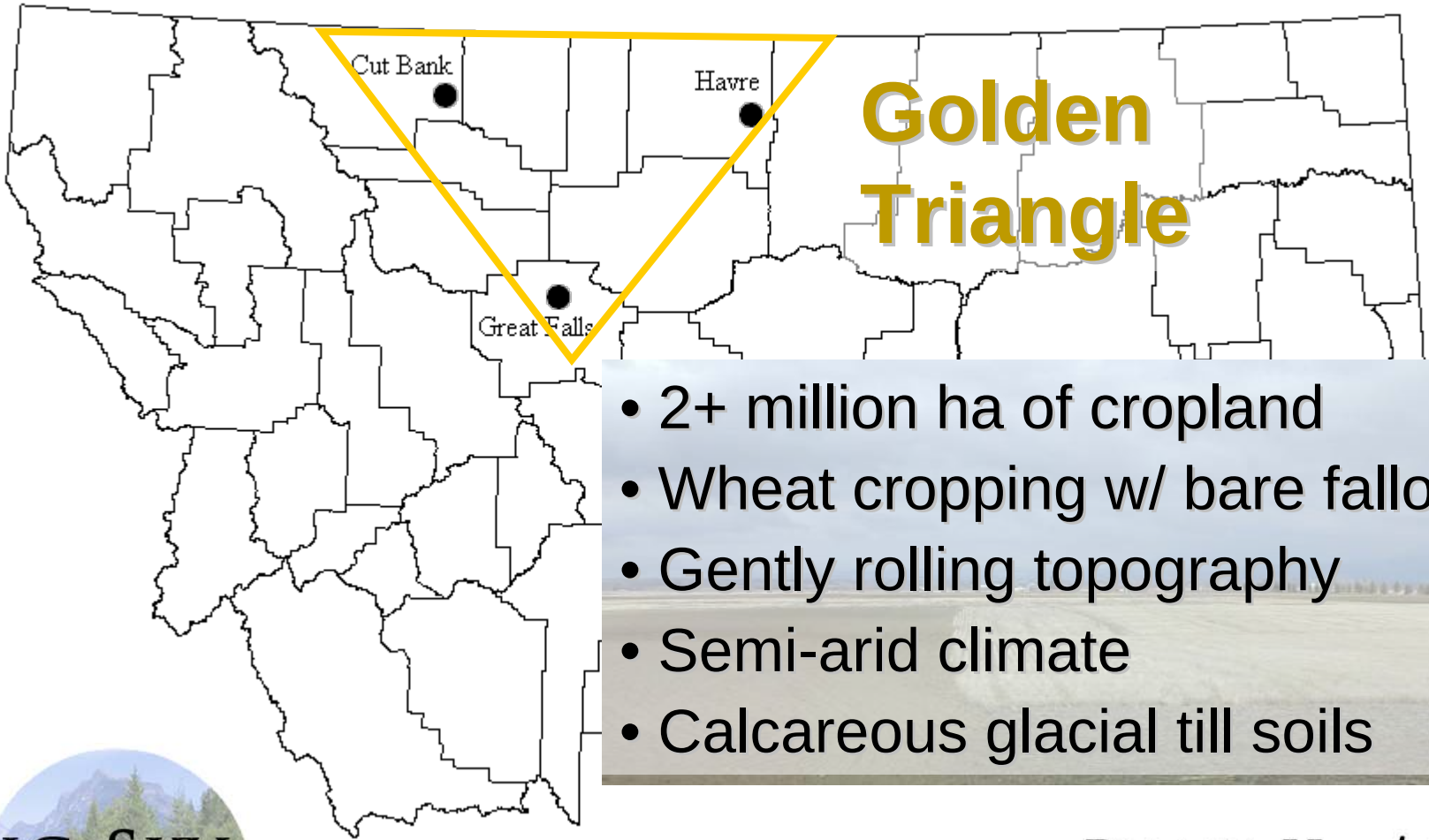
University of Wyoming

BIG SKY CARBON SEQUESTRATION PARTNERSHIP

PHASE II kick-off

DAVID BROWN - MONTANA STATE UNIVERSITY

North Central Montana Cropland



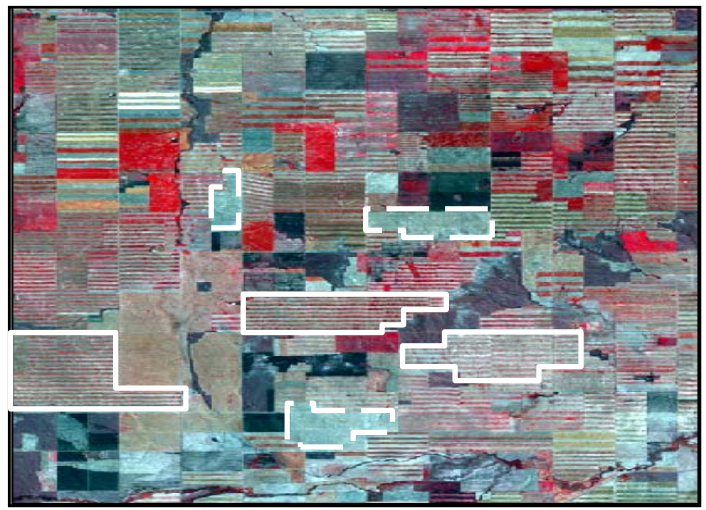
Golden Triangle

- 2+ million ha of cropland
- Wheat cropping w/ bare fallow
- Gently rolling topography
- Semi-arid climate
- Calcareous glacial till soils

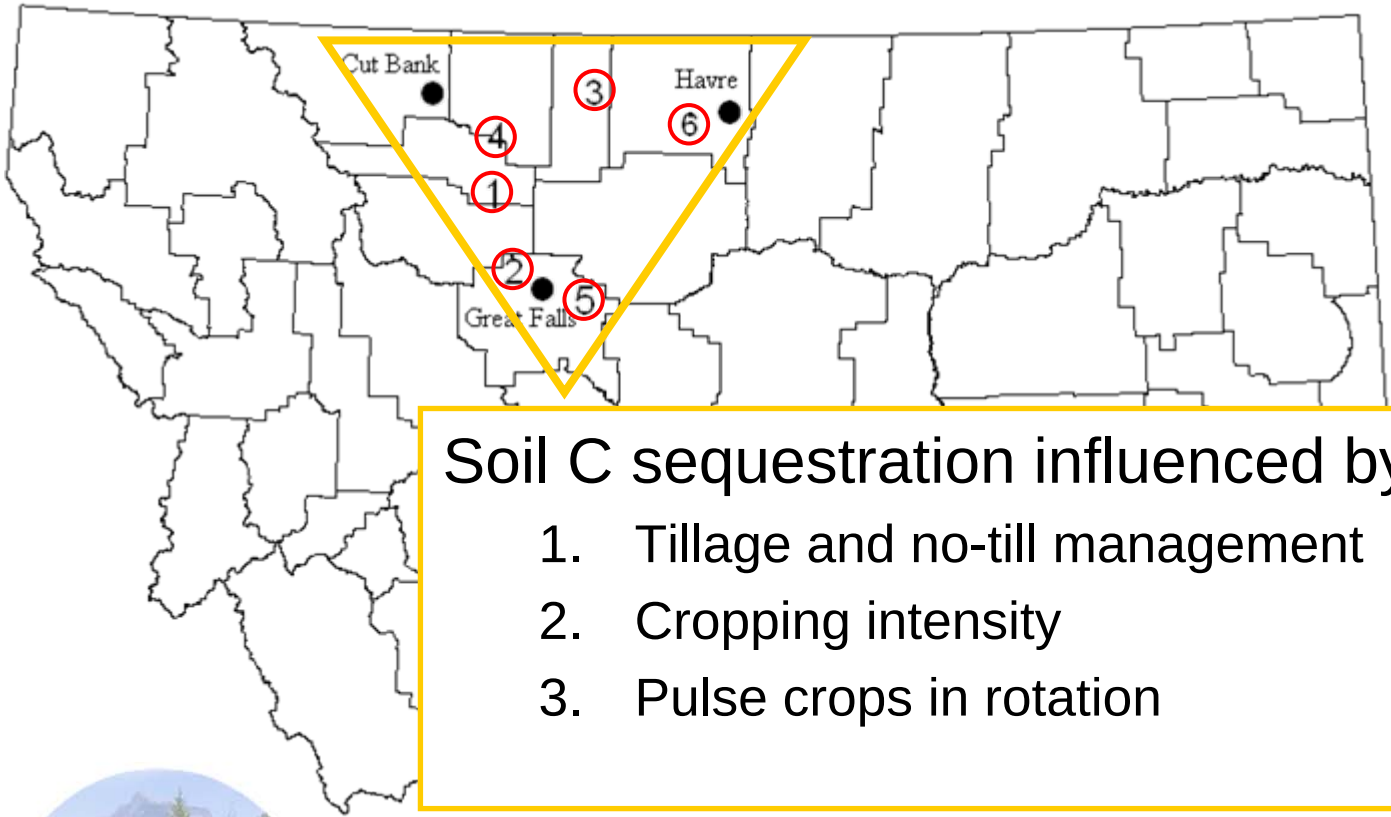
North Central Montana Cropland
Measurement Monitoring & Verification (MMV)

- Remote sensing (100% of enrolled farms)
  - Cropping system/intensity
  - Lookup tables for C sequestration
  - Century/Comet modeling

Controlled Experiments



North Central Montana Cropland
Controlled Experiments



Soil C sequestration influenced by:

1. Tillage and no-till management
2. Cropping intensity
3. Pulse crops in rotation

North Central Montana Cropland
Controlled Experiments

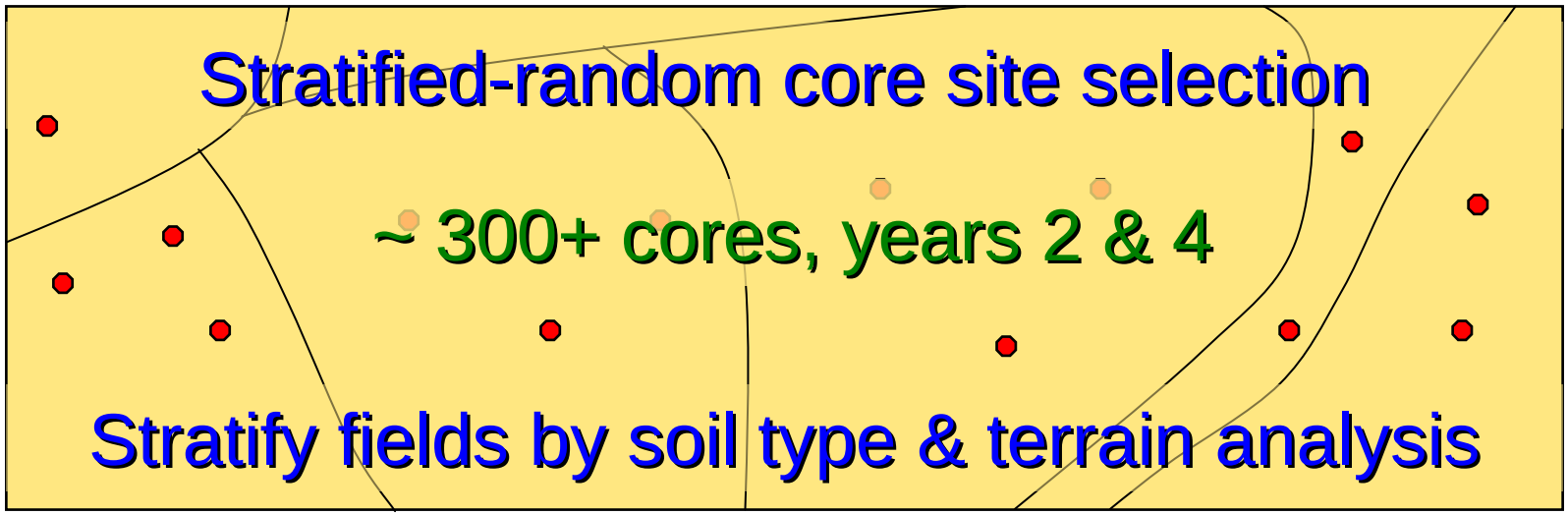
Sampling

1. Mature crop biomass sampled annually.
2. Soil organic carbon sampled after harvest biennially (even years).
3. C & N stable isotopes for gas emissions, crop, residue, and soil.

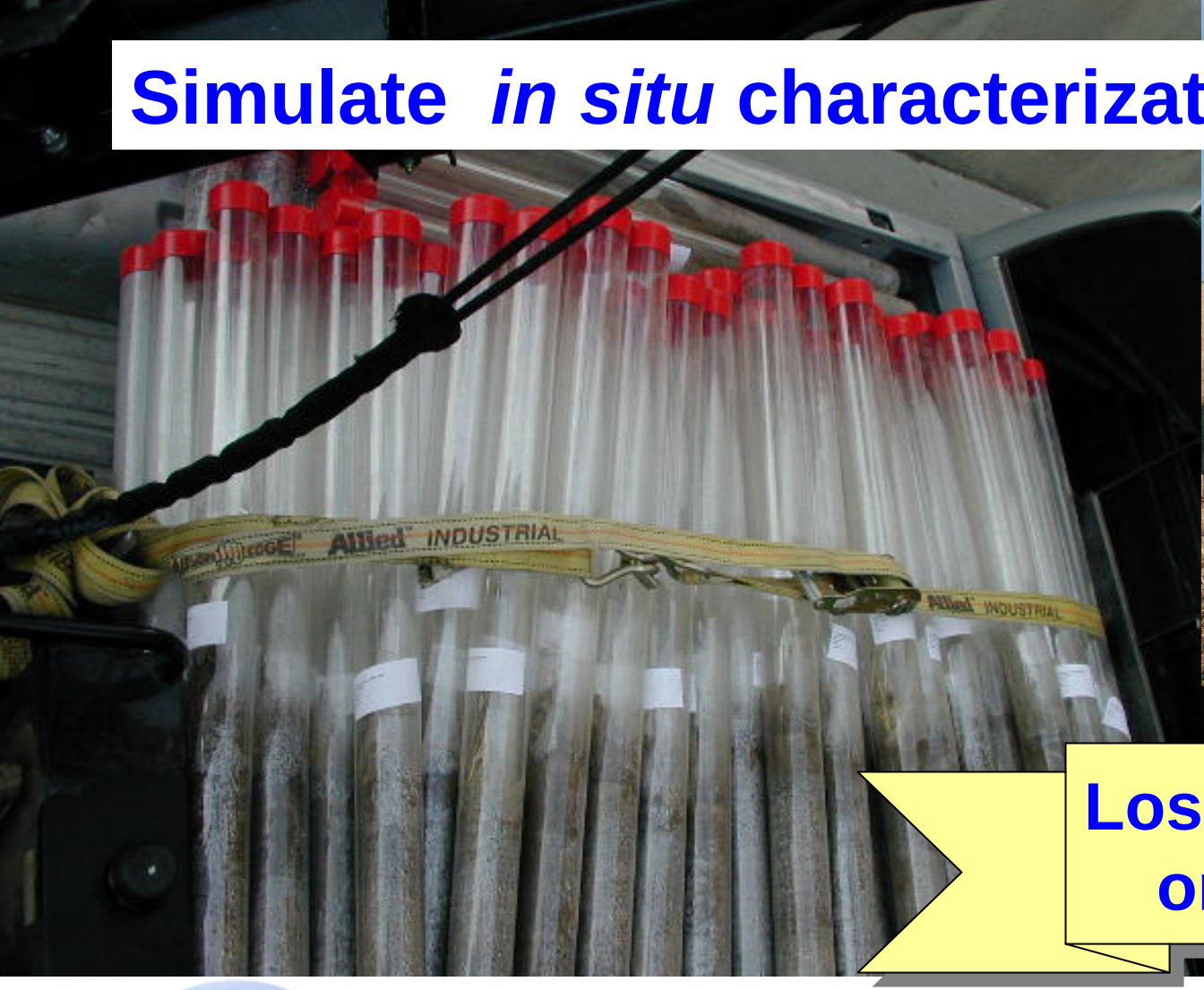
   (LANL, Julianna Fessenden)

North Central Montana Cropland
Measurement Monitoring & Verification (MMV)

- Direct measurements (~10 farms)

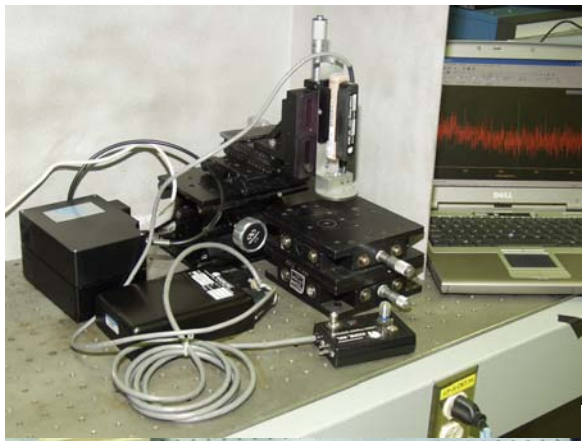


Simulate *in situ* characterization (MMV)



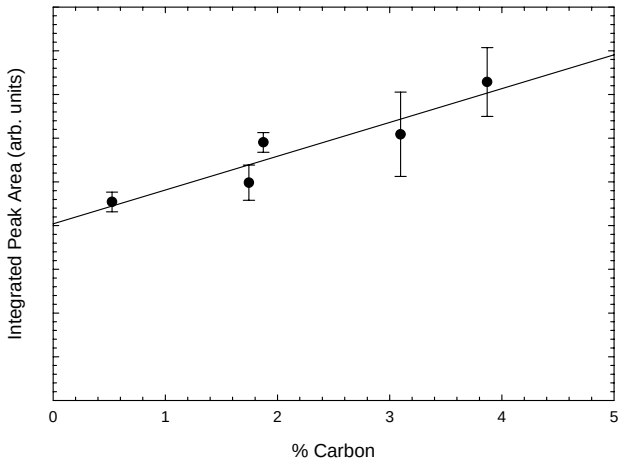
Los Alamos or Bust

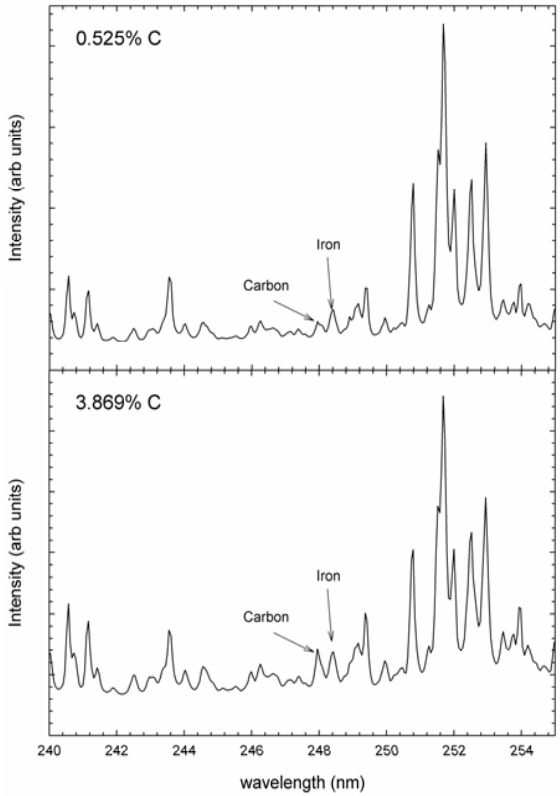
Laser-Induced Breakdown Spectroscopy (LIBS)



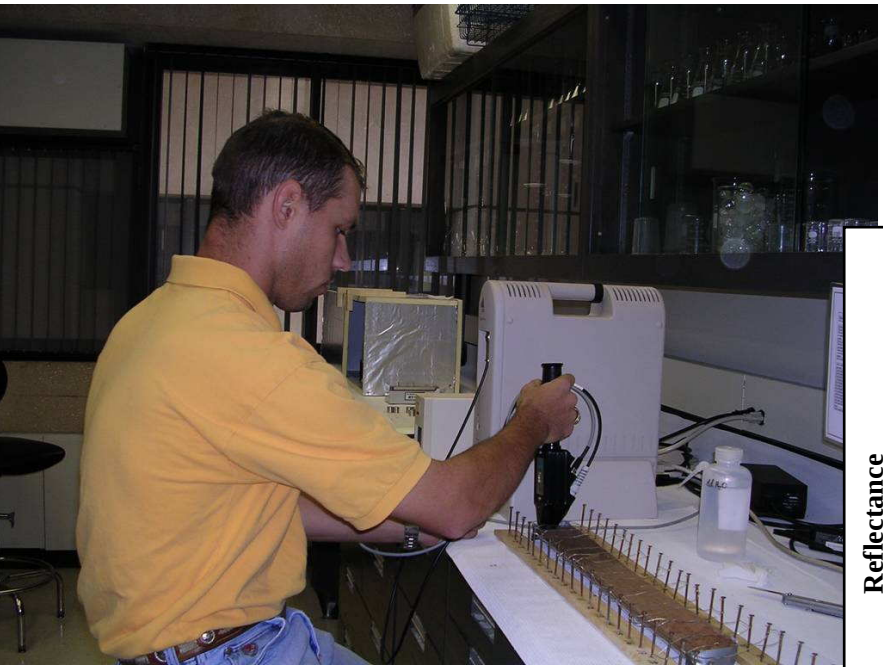
Scan Cores
Elemental C

MSU Student
LANL Sam Clegg



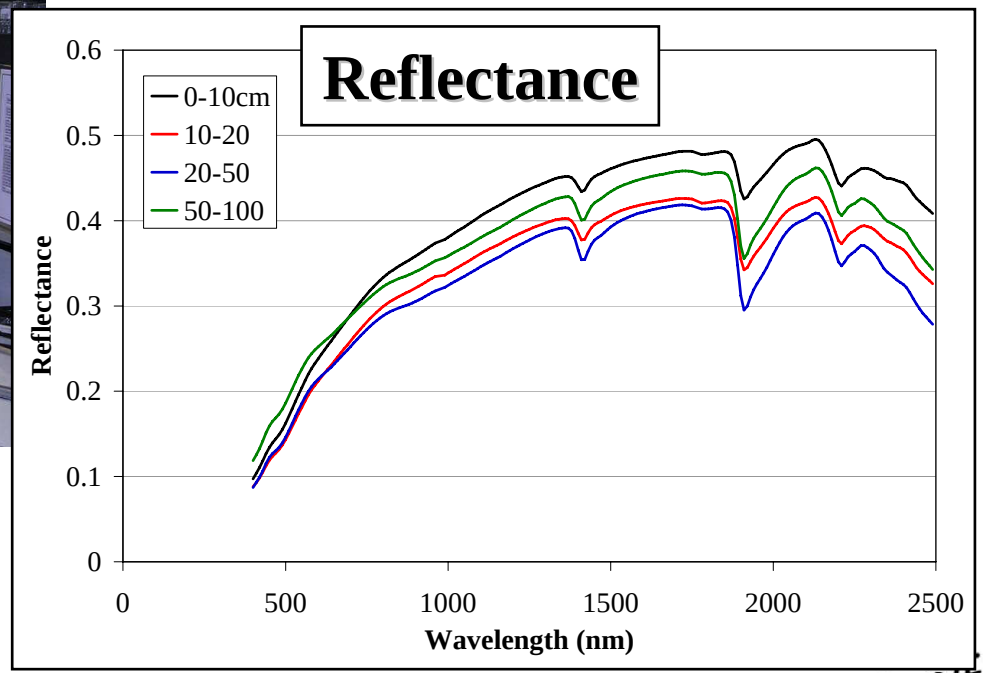


Visible and Near-Infrared (VNIR) Diffuse Reflectance Spectroscopy



Molecular technique

Organic vs. Inorganic C

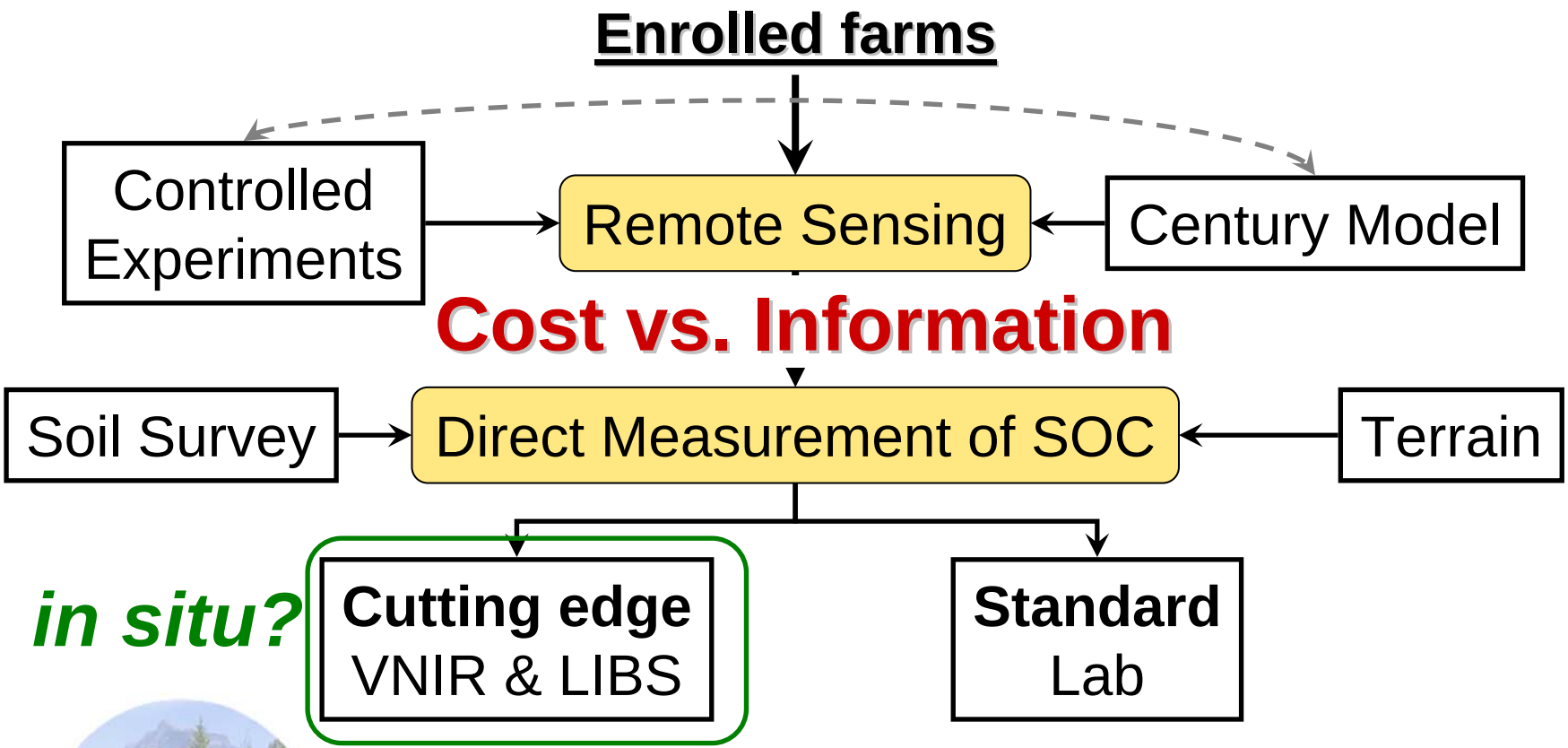


Standard Lab Analyses

Total Combustion
TOC

Pressure-Calcimeter
IC

North Central Montana Cropland
Measurement Monitoring & Verification (MMV)



OVERALL ADMINISTRATION

SUSAN M. CAPALBO -DIRECTOR (MSU)
ANGIE SOLVIE – PROGRAM ADMINISTRATOR (MSU)

TECHNICAL LEADS

REGULATORY COMPLIANCE
PAMELA TOMSKI (ENTECH) PUBLIC OUTREACH, EDUCATION & REGULATORY LEAD
DAVID SHROPSHIRE (INL) – CO-TECHNICAL LEAD

GEOLOGICAL SEQUESTRATION
ROBERT SMITH (UI) – TECHNICAL LEAD
TRAVIS MCLING (INL) – GEOLOGICAL OPERATIONS MANAGER
B.P. (PETE) MCGRAIL (PNWD)
SCOTT HUGHES (ISU)
JAMES STEIDTMANN (U WYO)
ERIC ROBERTSON (INL)

TERRESTRIAL SEQUESTRATION
DAVID BROWN (MSU) TECHNICAL LEAD
TED DODGE (NCOC) – CARBON MARKETS & TRADES, AND PROTOCOLS

MONITORING, MEASUREMENT & VERIFICATION
DICK BENSON (LANL) – TECHNICAL LEAD

GIS / CARBON ATLAS
RANDY LEE (INL) – CO-TECHNICAL LEAD
PAUL RICH (LANL) – CO-TECHNICAL LEAD

ECONOMIC / RISK ASSESSMENT
JOHN ANTLE (MSU) – TECHNICAL LEAD

BIG SKY
CARBON SEQUESTRATION PARTNERSHIP

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