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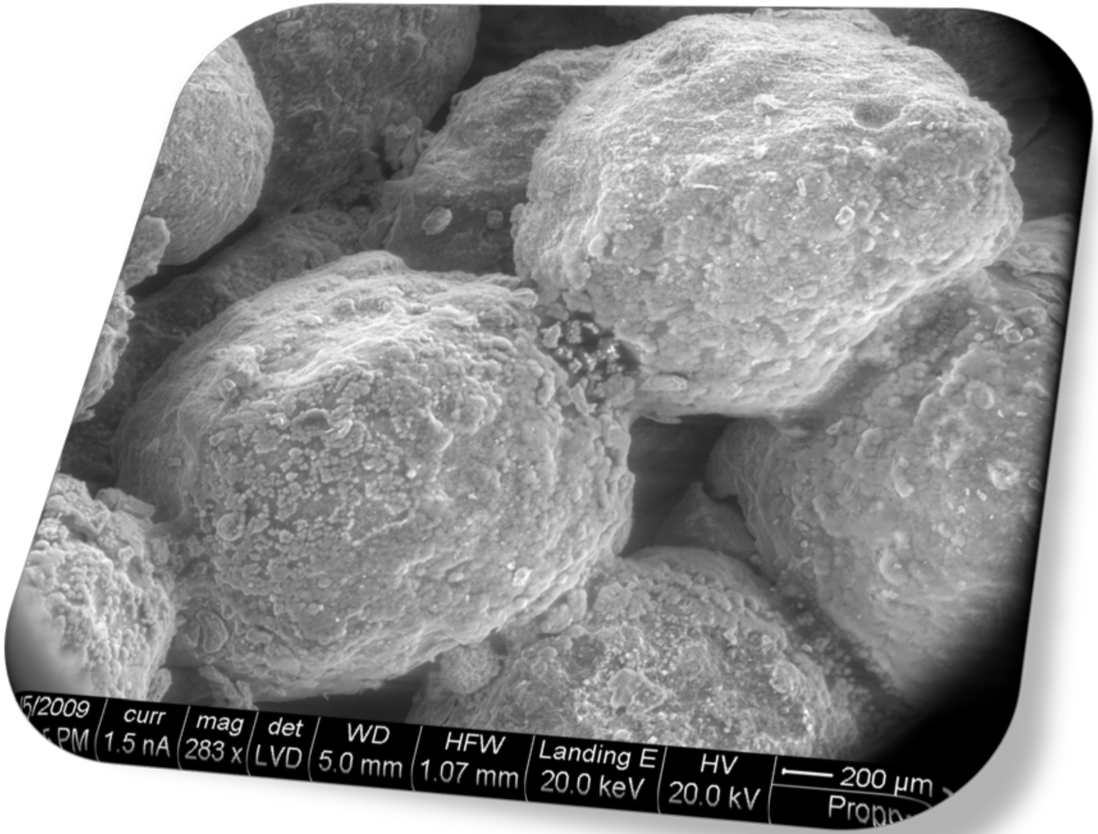


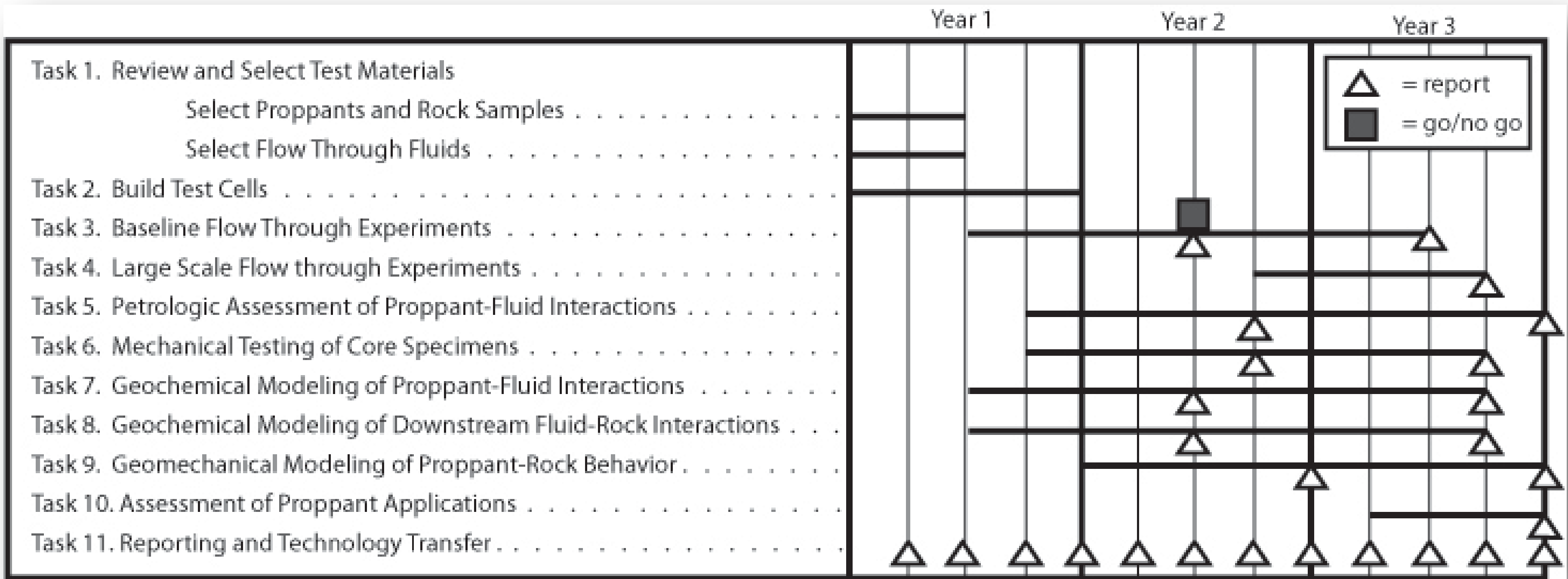
The Role of Geochemistry and Stress on Fracture Development and Proppant Behavior in EGS Reservoirs

May 18, 2010

Principal Investigator (Joseph Moore)
Presenter Name (John McLennan)
Organization University of Utah

Track Name Reservoir Characterization

Timeline



- **DOE Start Date:9/30/2008**
- **DOE Contract Signed: 9/26/2008**
- **Ends 11/30/2011**
- **Project ~40% Complete**

Budget Overview

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	DOE Share	Awardee Share	Total
Project Funding	$972,751	$243,188	$1,215,939
FY 2009	$244,869	$107,130	$351,999
FY 2010	$383,952	$64,522	$448,474
FY 2011	$343,930	$71,536	$415,466

- **DOE Start Date:9/30/2008**
- **DOE Contract Signed: 9/26/2008**
- **Ends 11/30/2011**
- **Project ~40% Complete**

- **Barriers to EGS Reservoir Development Addressed:**
  - Reservoir Creation
  - Long-Term Reservoir and Fracture Sustainability
  - Zonal Isolation
- **Partners**
  - Independent Evaluation

Relevance/Impact of Research

Problem

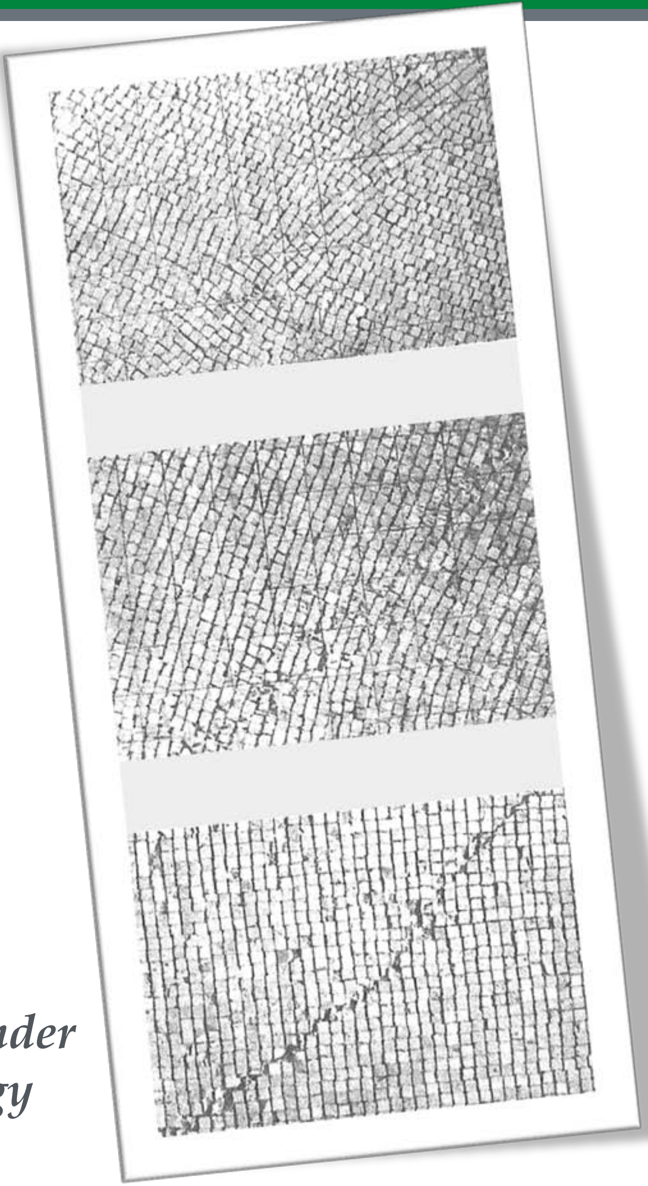
- Maximizing initial conductivity of EGS domains
- Maintaining long-term conductivity
- Facilitate development of extensive stimulated domain via diversion

Solution

- Proppant placed in fractures

Challenge

- Proppant behavior at geothermal conditions poorly understood



Use of proppant recognized as potential technology under Task "Keep Flow Paths Open" in DOE EGS Technology Evaluation Report

OBJECTIVE

Develop Improved Methods For Maintaining Permeable Fracture Volumes In EGS Reservoirs

- Experimentally evaluate performance under geothermal conditions (200^{o}C and depths to 10,000 ft)
- Effects of mineral deposition and dissolution on propped fractures
- Mechanical behavior of propped fractures
- Use of proppants and precipitates for diversion
- Geochemical effects on injected fluids
- Mechanical and geochemical simulation/prediction models for long-term conductivity

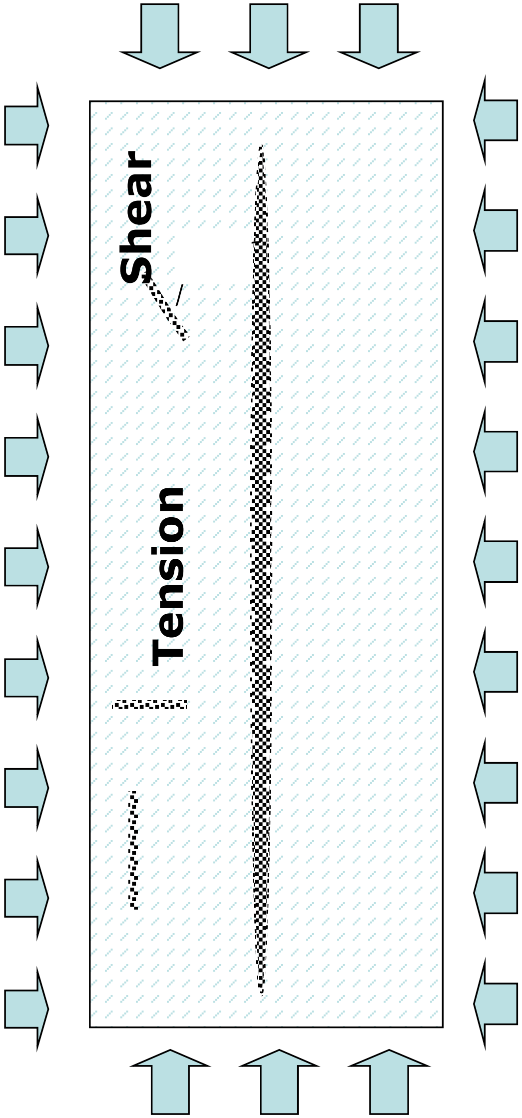
Relevance/Impact of Research

OBJECTIVE

Develop Improved Methods For Maintaining Permeable Fracture Volumes In EGS Reservoirs

ADDRESS CRITICAL NEEDS OF EGS RESERVOIR DEVELOPMENT

1. **Fracture Characterization**
2. **Zonal Isolation**
3. **Controlling Fracture Propagation**
4. **Predictive Modeling**



Expected Achievements

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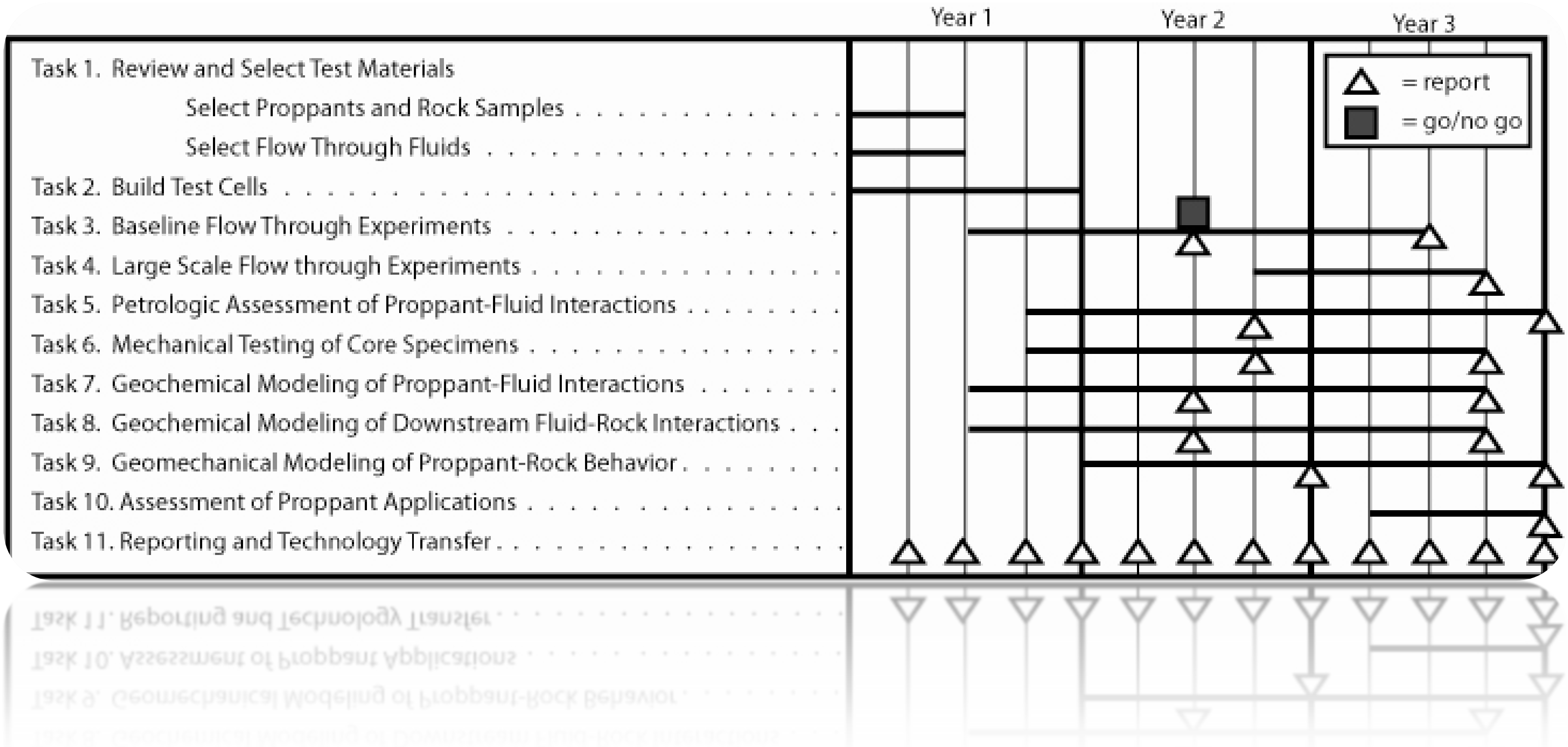
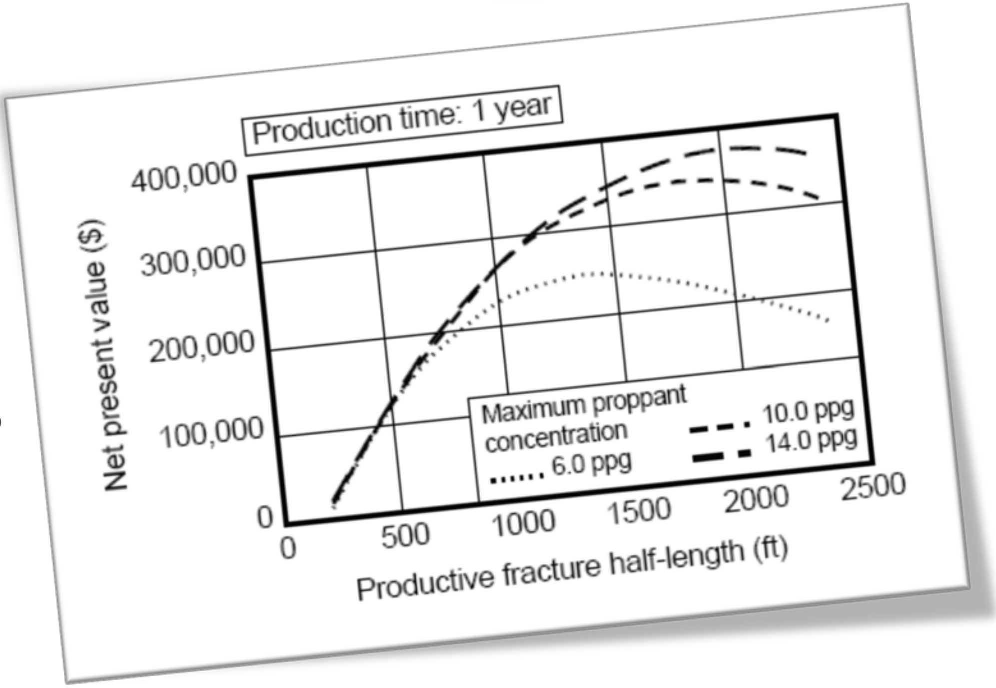


Impact of Research

- **Costs**
  - Treatment Costs Will Increase
  - Operational and Maintenance Costs Should Decline
  - Premium Proppant May Still Be Required
- **Performance**
  - Some Uncertainty
  - Control Potential For Scaling?
  - Scaling Spread Through Reservoir Rather Than Immediately at Wellbore?
  - Anticipate Conductivity Maintained?
  - Value in Intercommunication of Shear-Induced Fractures?

$$NPV = \sum_{n=1}^{n} \frac{\Delta \$_n}{(1+i)^n}$$



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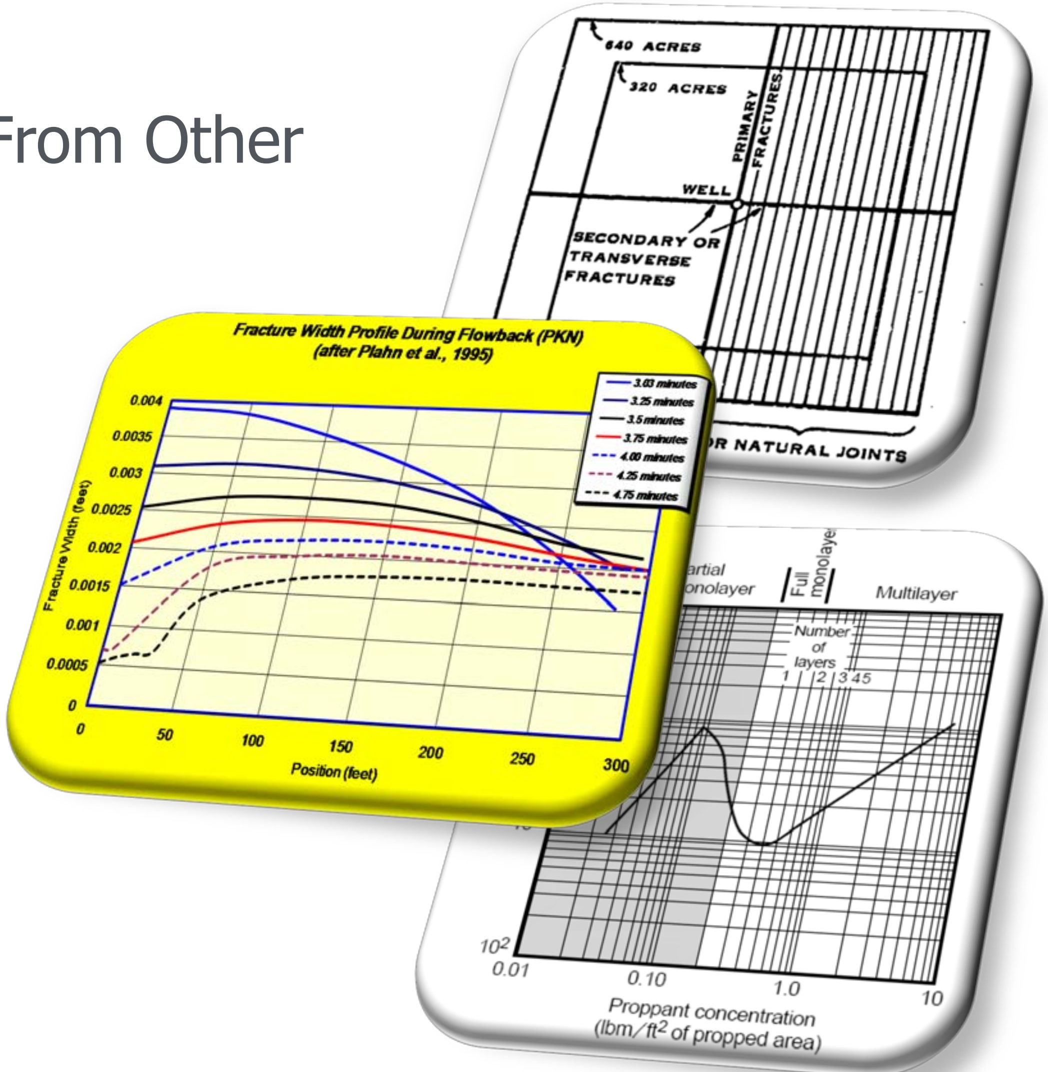
- **Proppant Applications**
  - **Diversion**
    [see Kiel, 1977]
  - **Diversion**
    [Fenton Hill, December 1983, $CaCO_3$]
  - **Scouring, Tortuosity Reduction**
    [Cleary, … Many Others]
  - **Conductivity Maximization**
    [Raymond and Binder, 1966]
  - **Conductivity Preservation**
    [Hassebroek and Waters, 1964]
  - **Surface Area and Efficiency**
    [Gas Shale Technology]
- **Markets**

> *When fracturing was first introduced, the value of the propping agent was not fully known, Theoretically it was a good thing, but some did not believe it to be essential. Comparative treatments with and without its presence soon demonstrated that. for sustained product ion increases, a proppant was important. Research has since substantiated these findings, and now the propping agent is considered a necessary ingredient incorporated in practically all treatments.*
>
> Hassebroek and Waters, 1964

Innovative Aspects of Project

- Applied Technologies From Other Disciplines
- In-Situ Conditions
- **NOT THE FIRST**
- Temperature
- Pressure
- Fluid Environment
- Geochemistry



Scientific/Technical Approach

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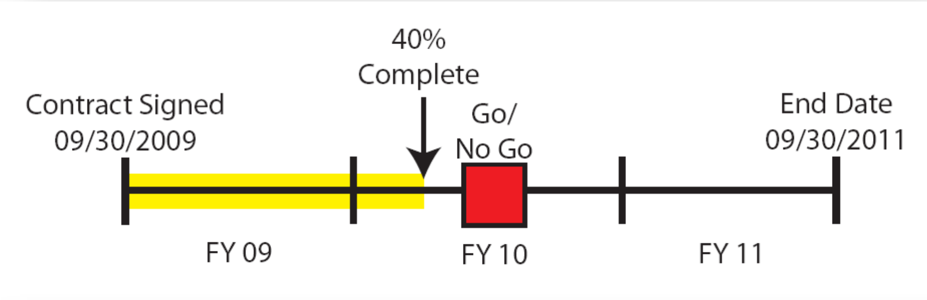
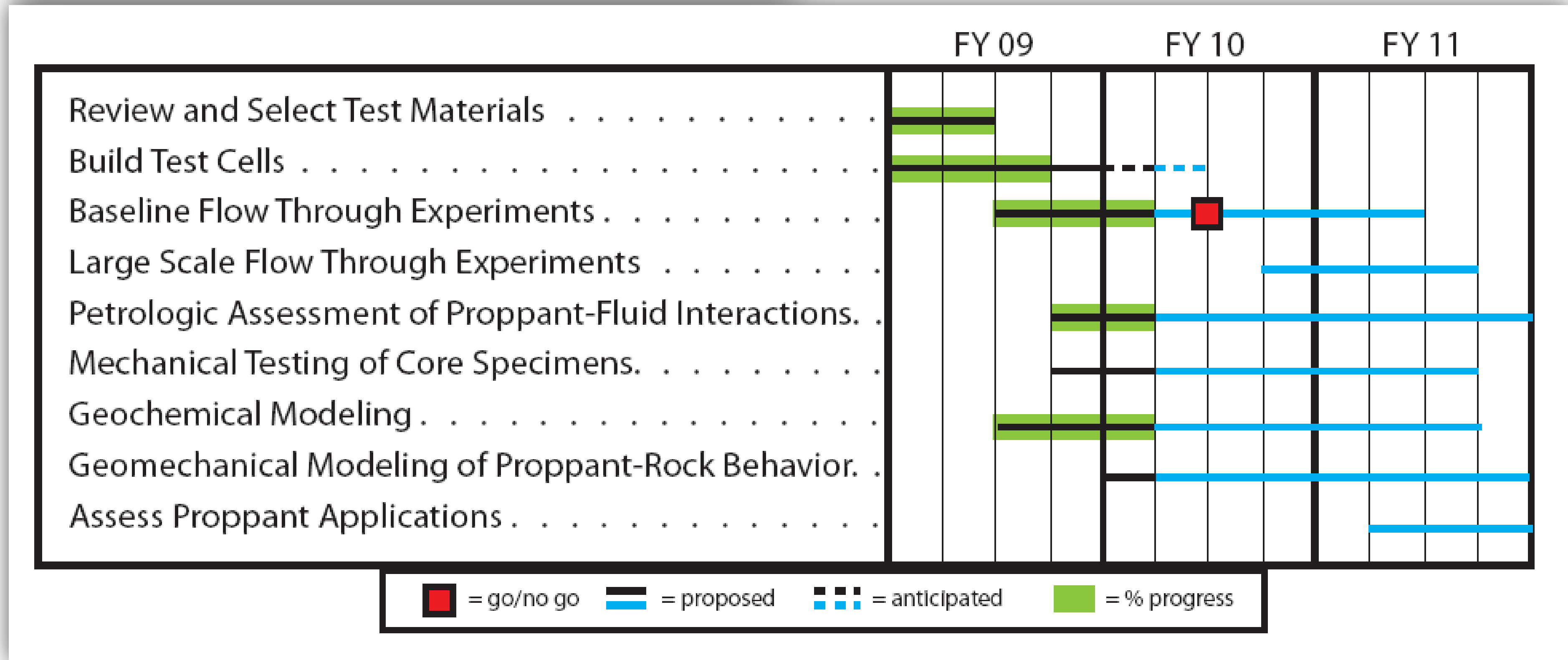
- **Tasks 1-3**
  - Select appropriate rocks, fluids and proppants for testing
  - Infer/Determine chemomechanical effects through baseline tests
    - Ambient temperature conductivity measurements
    - Static, long-term exposure to representative temperature
  - Design and fabricate high-temperature conductivity apparatus
- **Tasks 4-7**
  - Conductivity measurements at temperature and pressure
  - Measure conductivity and chemical changes to constrain geochemical and geomechanical models
  - Back-analysis and modeling
- **Tasks 8-11**
  - Large scale flow conductivity measurements
  - Compile and interpret mechanical and geochemical data
  - Assess applications of proppants in geothermal reservoirs

Milestones and Go/No Go





Qualifications and Facilities

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EGI:

- **J. Moore: Principal Investigator:** geothermal geology, geochemistry, hydrothermal alteration
- **J. McLennan:** Rock mechanics, rock property measurements, fracture stimulation in oil and gas/geothermal industry
- **Students:** D. Brinton (B.S./M.S), K. McLin (Ph.D.), J. Carnell (M.S.), T. Stoddard (B.S./M.S.), Prashanth Mandalaparty (Ph.D.)

Dept. of Chemical Engineering, University of Utah

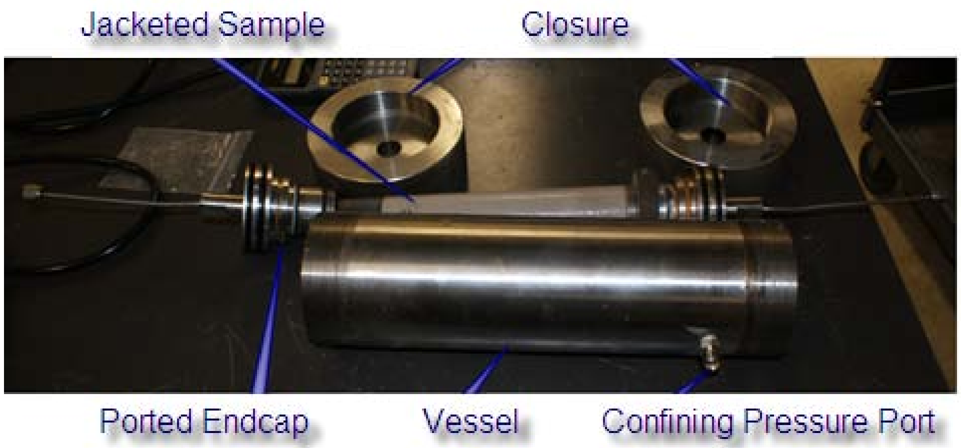
- **M. Deo:** Reservoir engineering, rock property measurements, numerical simulation of fracture-fluid behavior

Available Facilities

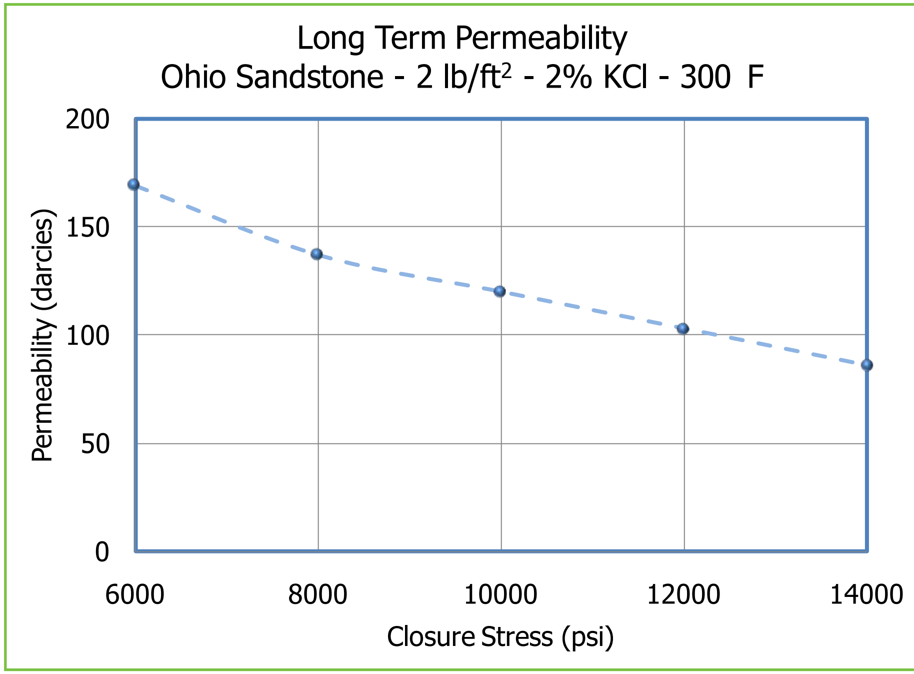
- Laboratories for experimental studies at P and T
- Machine Shops
- SEMs, QEMSCAN, XRD, ICP-MS (water analyses) ….

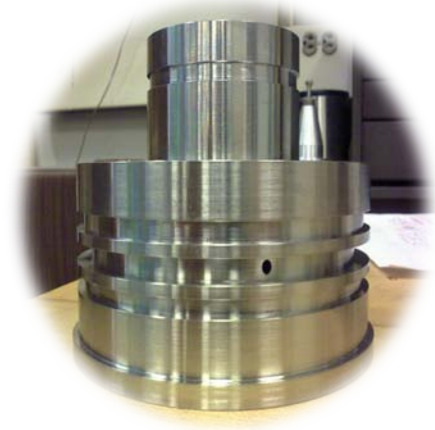
Conductivity Measurements

- Non-API apparatus – intentionally
- Capable of 200° C but currently running at ambient temperature
- 30/60 Bauxite
- Granodiorite
- Saw-Cut and **SPLIT**
- **ROUGH SURFACE IMPORTANT**

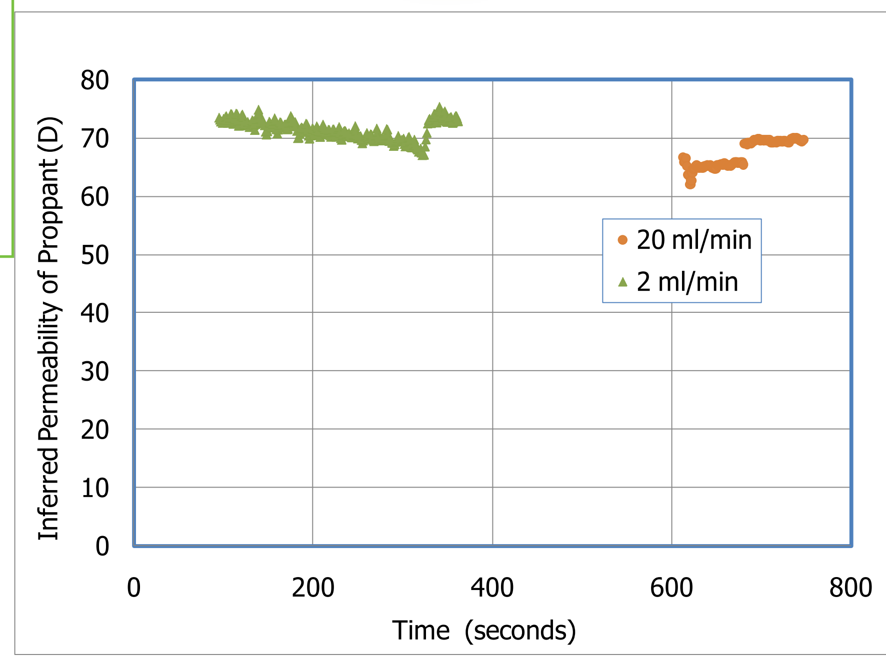


Accomplishments, Expected Outcomes and Progress





- Reduced Conductivity Attributed to Surface Roughness
- Fracture Tortuosity
- Inertial Restrictions

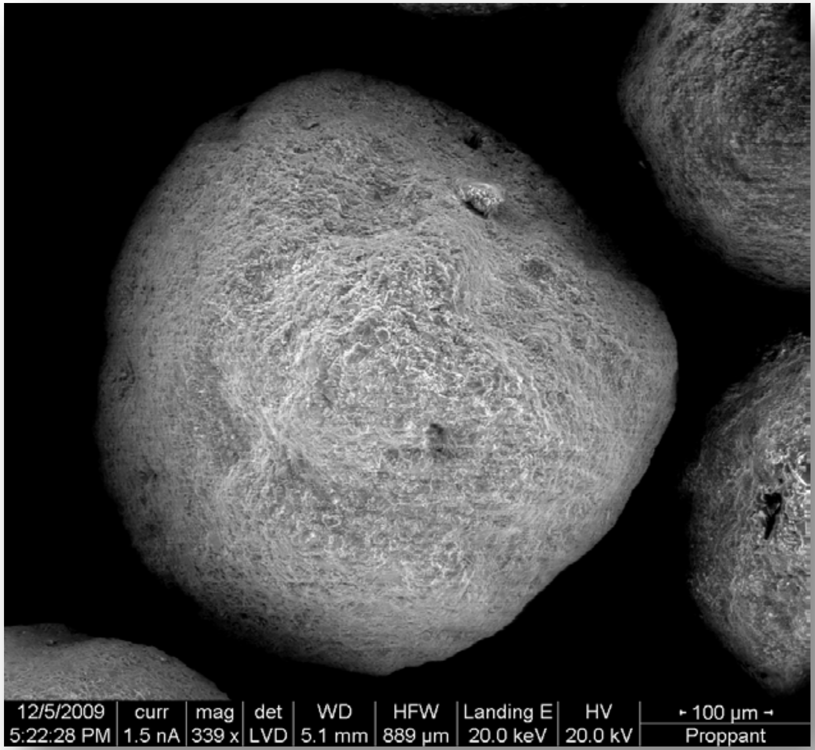


Static Exposure To Fluid At Temperature

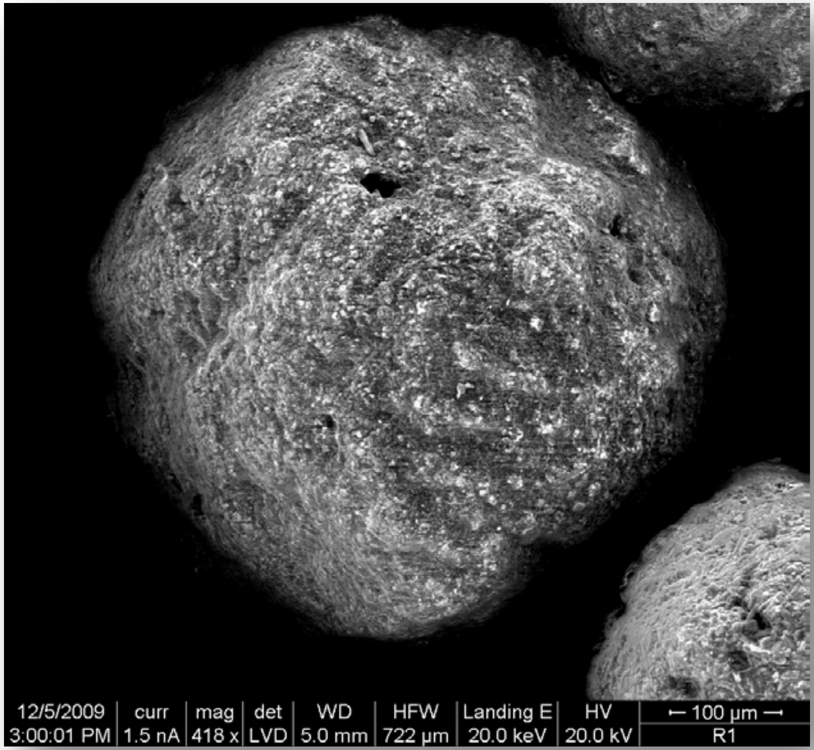
Series	Solids	Liquid	Temperature (°C)	Duration (weeks)
1	Proppant	DI Water	200	~4
2	Proppant	DI Water	200	~8
3	Proppant/Crushed Granite	DI Water	200	10
4	Proppant/Crushed Granite	DI Water spiked with silica	200	on-going
5	Proppant/Crushed Granite	DI Water spiked with silica	200	on-going

Surface Corrosion

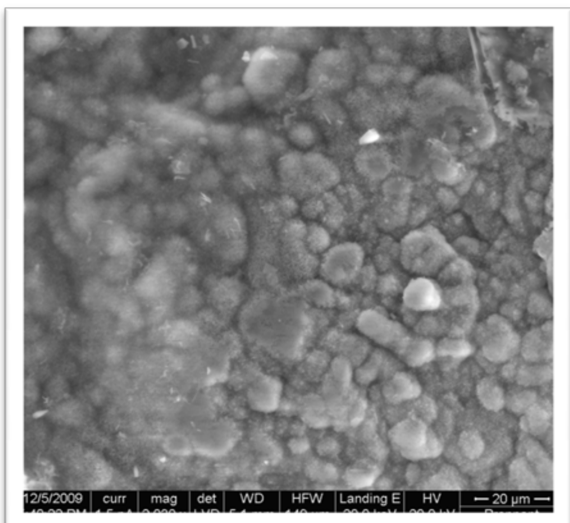
"Fresh" Proppant (Typical)



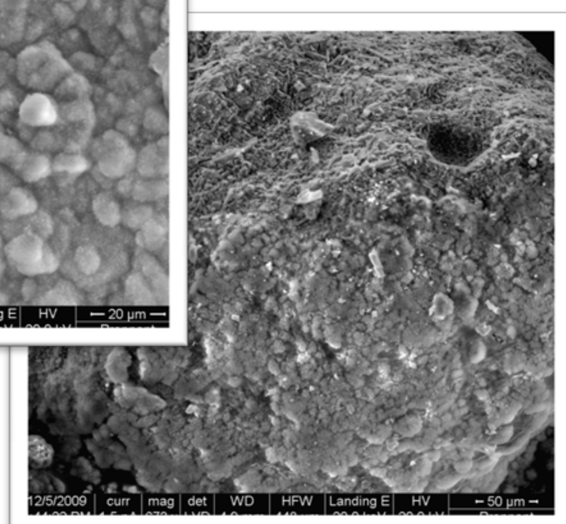
After One Month (Typical)

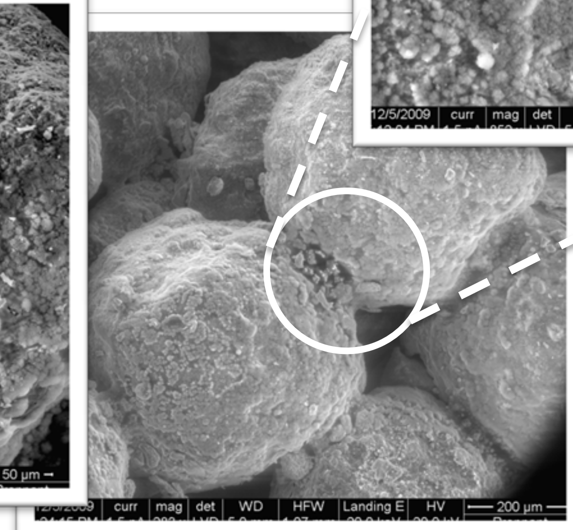


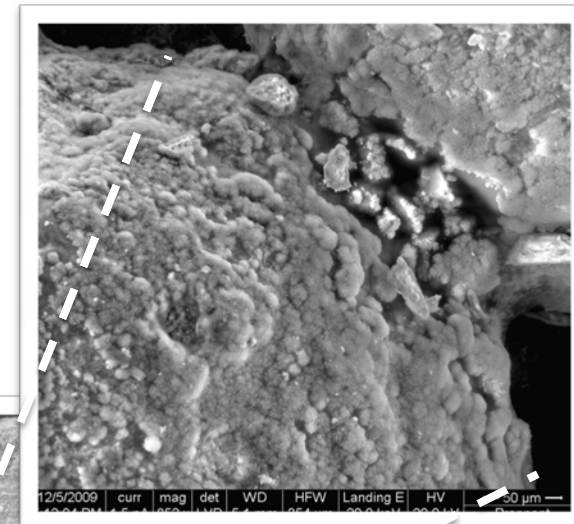
1. Mobilization of Minerals
2. Re-Precipitation on Proppant
3. Cementation of Proppant



Two-Month Exposure







Project Management/Coordination

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Management Activities Principal Investigator: J. Moore

- Responsible for overall management of project
- Establish schedules
- Prepare DOE reports
- Point of contact with DOE Project Managers

Application of Leveraged Funds

- Students

Integration with Other Projects in Program?

- Could be implemented at any field demonstration
- Was proposed at Raft River

Coordination with Industry & Stakeholders

- Independent assessment – no manufacturers or service companies

Future Directions

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FY10 Activities

- Complete fabrication of high temperature vessel
- Initiate experiments at P and T
  - Obtain conductivity data
  - Roughness modeling and implications
- Continue experimental studies in static mode and collection of geochemical data
  - Analyze reacted water
- Geochemical modeling of water-rock interactions

Future Directions

FY11 Activities

- Complete experimental studies
- Conduct large scale conductivity tests
- Compile and interpret mechanical and geochemical data
- Assess proppant applications

Summary

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- Few legacy geothermal applications of proppant
- Behavior at geothermal conditions uncertain
- Study well defined, addresses specific critical questions, and technically feasible
- Project conducted by highly qualified and experienced scientists and engineers from geothermal and oil and gas industries with expertise in geochemistry, rock mechanics, and reservoir stimulation
- Excellent facilities to conduct study
- Significant progress since project initiated
- Project on schedule
- Significant student involvement in project
- Students are conducting original research
- Several oil and gas and service companies interested