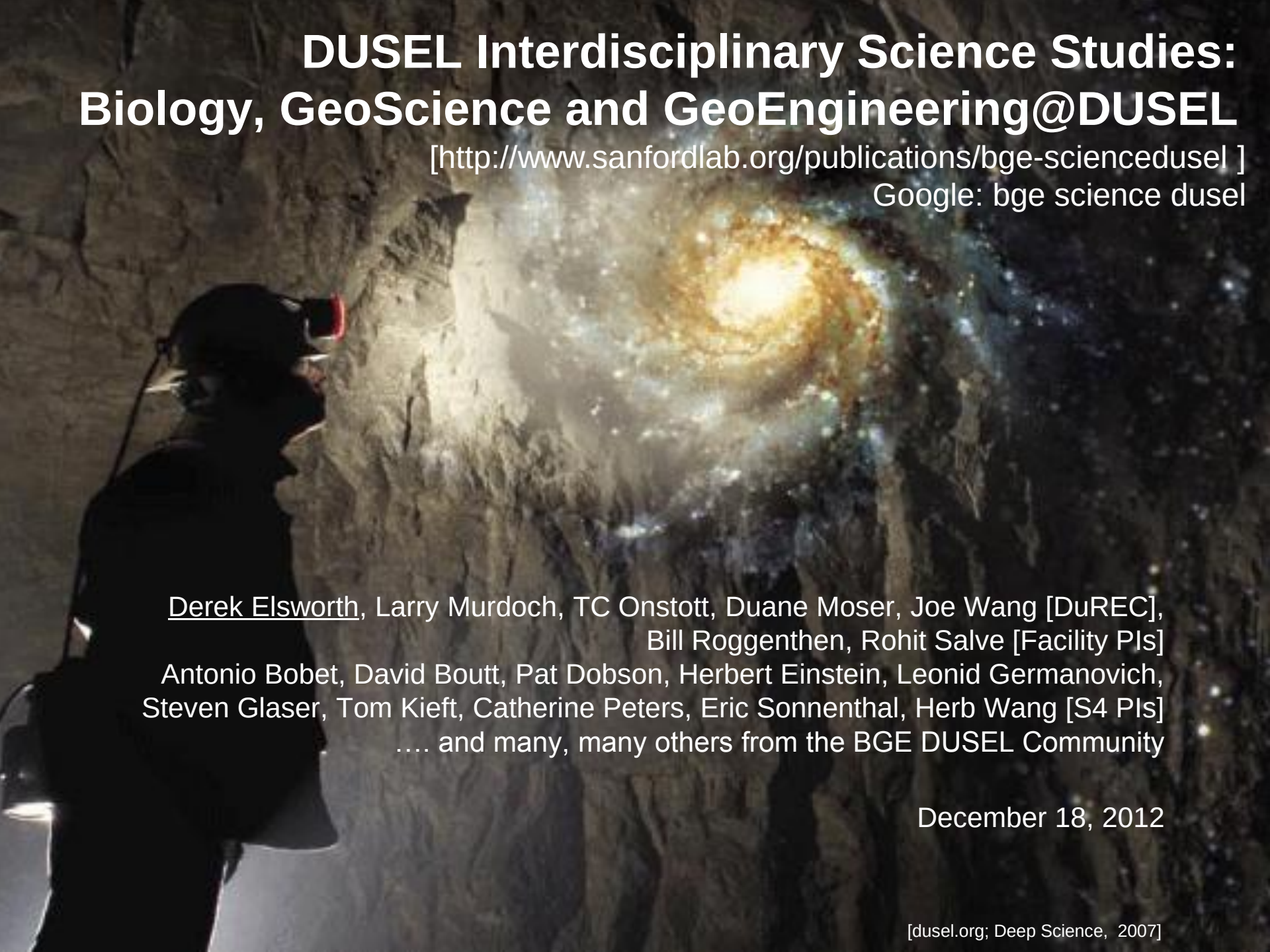
DUSEL Interdisciplinary Science Studies: Biology, GeoScience and GeoEngineering@DUSEL

[http://www.sanfordlab.org/publications/bge-sciencedusel]
Google: bge science dusel



Derek Elsworth, Larry Murdoch, TC Onstott, Duane Moser, Joe Wang [DuREC],
Bill Roggenthen, Rohit Salve [Facility PIs]
Antonio Bobet, David Boutt, Pat Dobson, Herbert Einstein, Leonid Germanovich,
Steven Glaser, Tom Kieft, Catherine Peters, Eric Sonnenthal, Herb Wang [S4 PIs]
…. and many, many others from the BGE DUSEL Community

December 18, 2012

[dusel.org; Deep Science, 2007]

Outline

- Societal Imperatives for Geo-Science and Geo-Engineering (Needs)
- Science Drivers (Objectives)
  - Underground Universe (Physics and Astrophysics)
  - Dark Life (Biology)
  - Restless Earth (Geoscience)
  - Ground Truth (Geoengineering)
- DUSEL Initial Suites of Experiments (Approaches)
  - Distributed Experiments [FiberOptic/EcoHydrol/Drilling/Transp. Earth]
  - Facility-Based Experiments [CO2/THMCB/Frx]
  - Cavity Experiments
- Facility Layout with Experiments
- The Future of DUSEL? (Outcomes)

Evolution of DUSEL and Its BGE Community

2000: Homestake closure announcement. Meeting with Earth science and physics communities

2001: Underground Science Meetings; Earth science, physics and geomicrobiology workshops

2002: NSF visit, ARMA/NRC and NeSS meeting [200 BGE participants]

2003: ARMA-NSF and EarthLab reports; ISRM-DUSEL Workshop; J'burg

2004: NSF S-process announcement, S-1 workshops

2005: S-2 applications,
H-H selection + 2, AGU townhall, S-2 workshops

2007: S-3 Homestake award; ISRM-DUSEL Workshop, Lisbon

2008: Development of ISE - DEDC

2009: S-4 Science awards [~230 Physics/~71 BGE senior investigators]

2010: S-4 Science awards completed

2010: DEDC transitions to DuRA [~700 physicists + ~300 BGE]
Program Advisory Committee (PAC) formed
NRC Review (Dec 2010)

2011: NSF-> DOE Program Review
MREFC to NSF and National Science Board – then Congress

2013+: Initial experimental activities scheduled to begin

Scientific Rationale and Societal Imperatives

Fill the Stabilization Triangle with Seven Wedges

Renewable Electricity and Fuels

Zero carbon: 800 GW (~40 tcf/yr)

CO_2 Capture and Storage

Zero carbon: 800 GW (~40 tcf/yr)

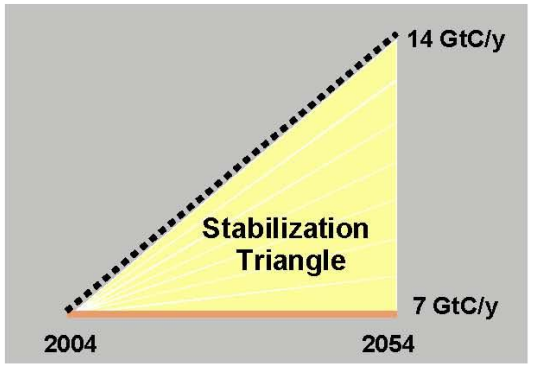
Energy Efficiency & Conservation

2 billion cars at 60 mpg instead of 30 mpg

Forests & Soils

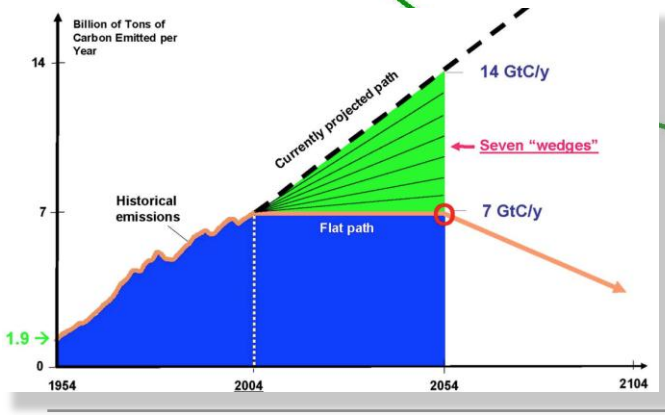
Fuel Switch

Low carbon: 1600 GW (~80 tcf/yr)



Nuclear Fission

Zero carbon: 700 GW (~40 tcf/yr)



[**Rationale in:** Pacala & Socolow, *Science*, 2004, www.stabilisation2005.com/day3/**Socolow**.pdf]

Example: Zero Carbon Solution? Enhanced Geothermal Systems

Requirements

- Geothermal gradient
- Natural/induced fracturing

Attributes

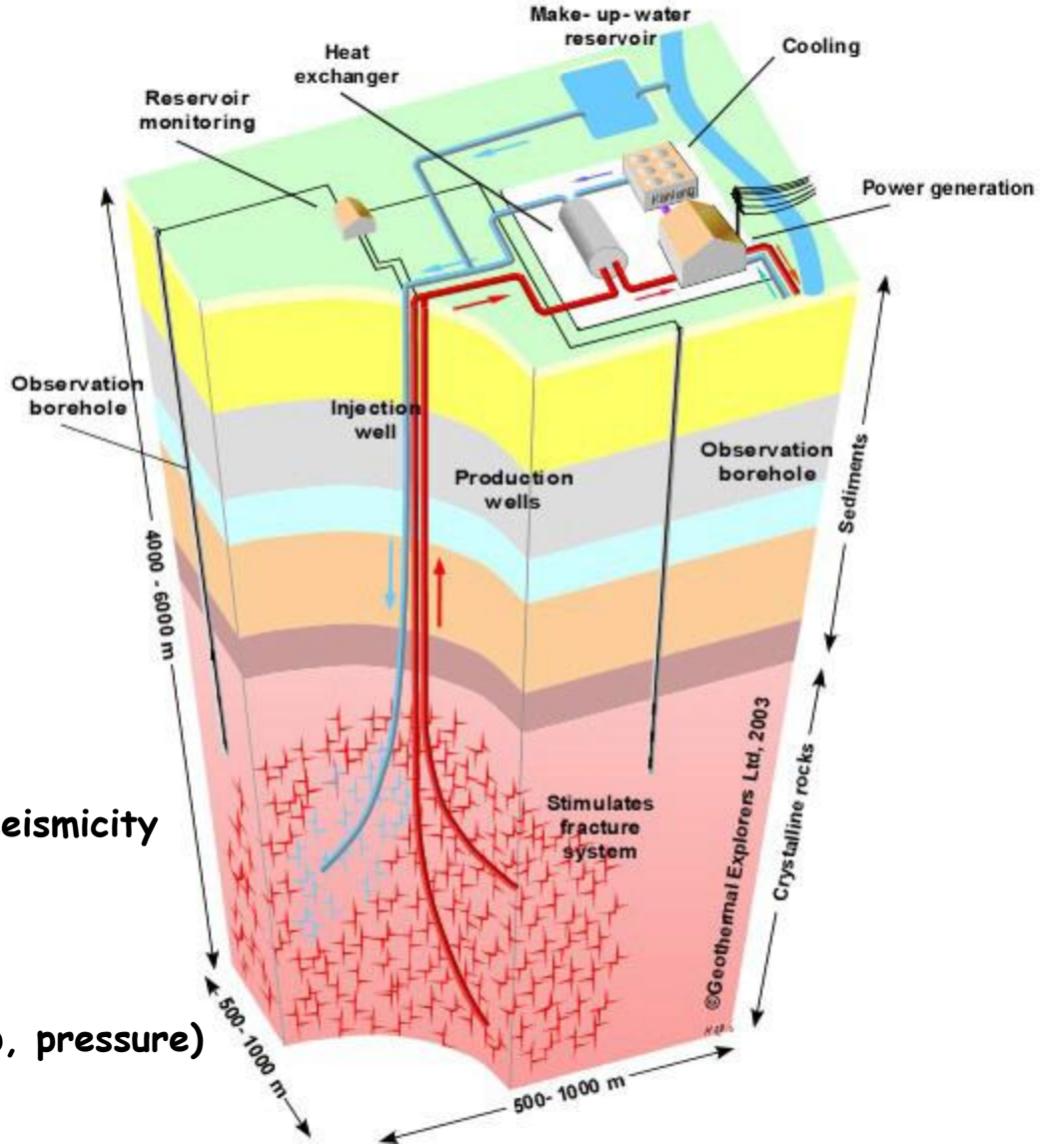
- Large scale
- Sustainable
- Peak load available
- Virtually emission free
- Small surface footprint

Challenges

- Prospecting (characterization)
- Accessing (drilling)
- Creating reservoir
- Sustaining reservoir
- Environmental issues – e.g. induced seismicity

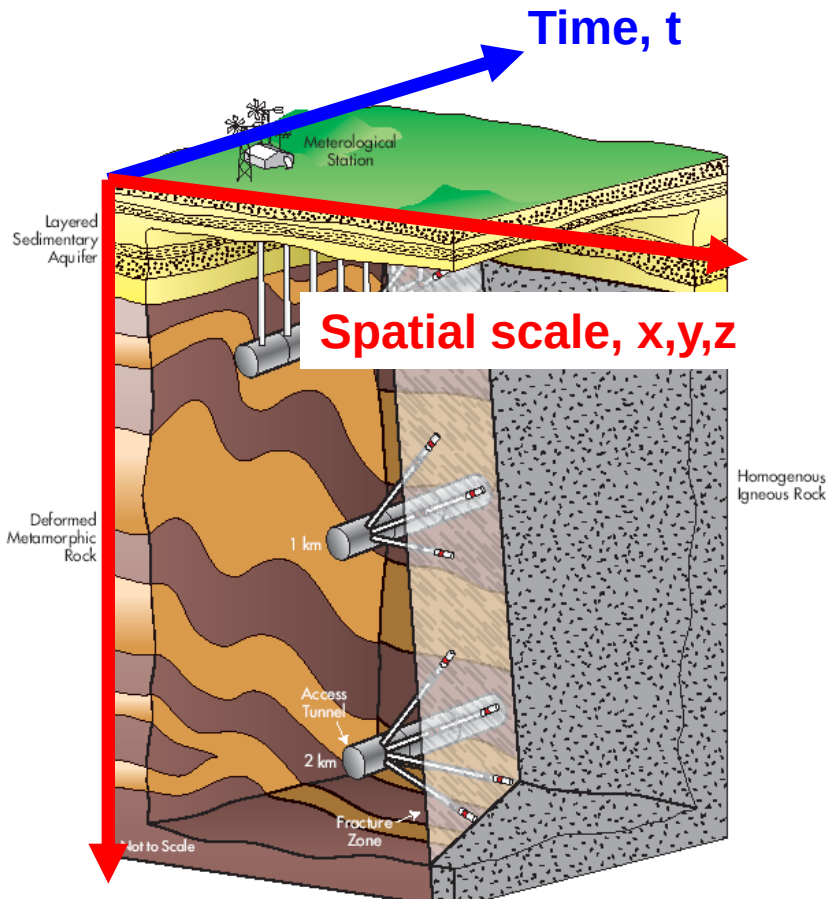
Intrinsic Attributes

- Scale dependent
- Environment dependent (stress, temp, pressure)
- Time dependent



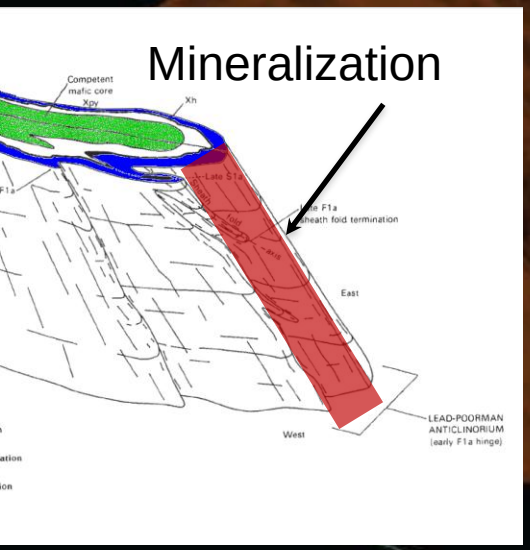
Principal Attributes of a DUSEL

- Broad access to an opaque block of rock (~km-scale)
- Depth and hence elevated stresses and temperatures
- Long-term occupancy, hence continuity



Depth, z -> Στρεσσ ανδ Τεμπερατυρε

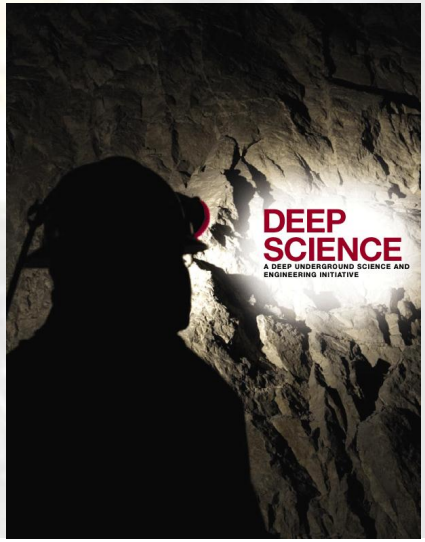
Facility – Sanford/Homestake Laboratory



$1km^3$

Biology, Geosciences, Engineering – S1 Science Drivers

- Dark Life (Biology)
  - How deep does life go?
  - Do biology and geology interact to shape the world underground?
  - How does subsurface microbial life evolve in isolation?
  - Did life on earth originate beneath the surface?
  - Is there life on earth as we don't know it?
- Restless Earth (Geosciences)
  - What are the interactions among subsurface processes?
  - Can we view complex underground processes in action?
  - Can we forewarn of earthquakes?
- Ground Truth (Geoengineering)
  - What lies between boreholes?
  - How can technology lead to a safer underground?
  - How do we better harness deep underground resources?



Biology-Geosciences-Engineering Summary Experiments

LONGSECTION OF THE HOMESTAKE MINE

Distributed Experiments

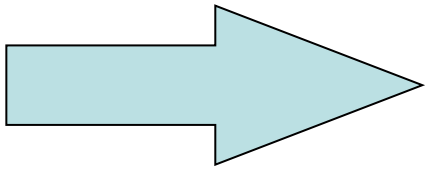
CMMI Fiber-Optic Monitoring of R. Masses	Wang (UWM) + 6 others	**[CMMI+GEO]**
S4 Deep EcoHydrology	Boutt (UMass); Kieft (NMT); Wang (UWM) + 8 others	**[CMMI+GEO]**
S4 Subsurface Imaging and Sensing	Glaser (UCB) + 19 others	**[CMMI+GEO]**

Facility-Based Experiments

S4 CO_2 Sequestration (LUCI)	Peters (Princeton); Oldenberg/Dobson(LBNL) + 6 others	**[CMMI+CBET]**
CMMI Coupled THMCB Processes	Sonnenthal (LBNL) + 6 others	**[CMMI+GEO]**
S4 Faulting Processes (FRX)	Germanovich (Georgia Tech) + 7 others	**[CMMI+GEO]**

Cavity Experiments

S4 Cavern Design for DUSEL	Einstein (MIT); Bobet (Purdue) + 8 others	**[CMMI+GEO]**

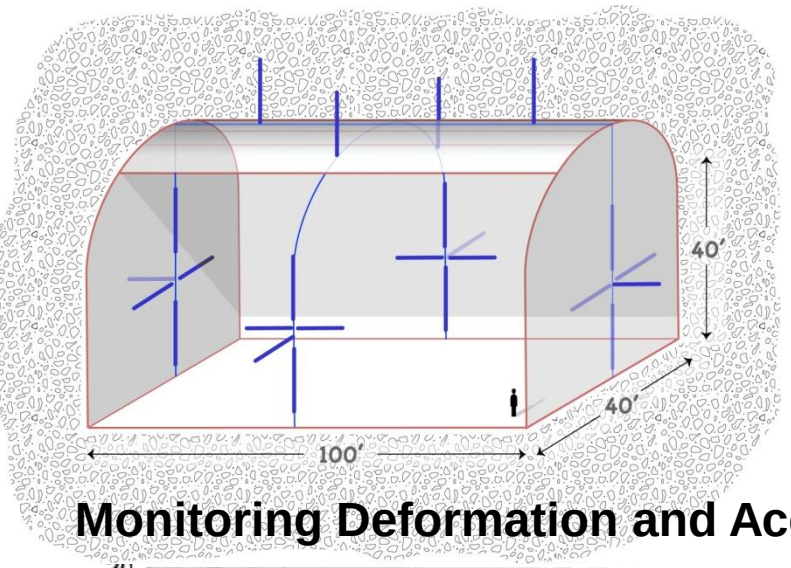


have a strong interactions with Physics research

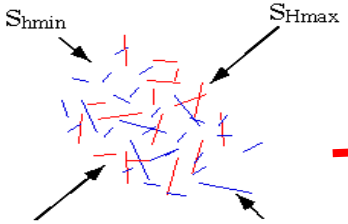
DISTRIBUTED EXPERIMENTS [FIBEROPTIC/ECOHYDROLOGY/DEEP DRILLING/TRANSPARENT EARTH]

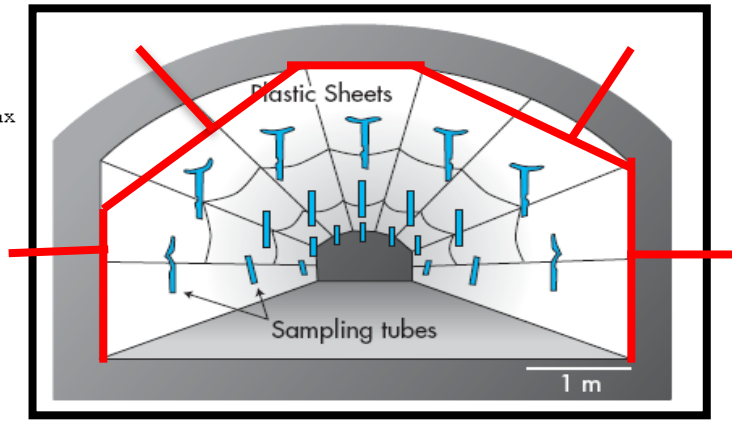
Fiber-Optic Strain and Tilt Monitoring of Rock Masses in Large Underground Facilities - GEOX™

Large Scale Deformability

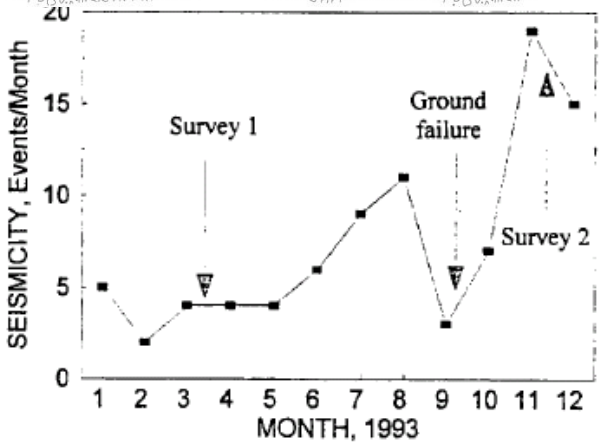


Linking Deformability and Permeability



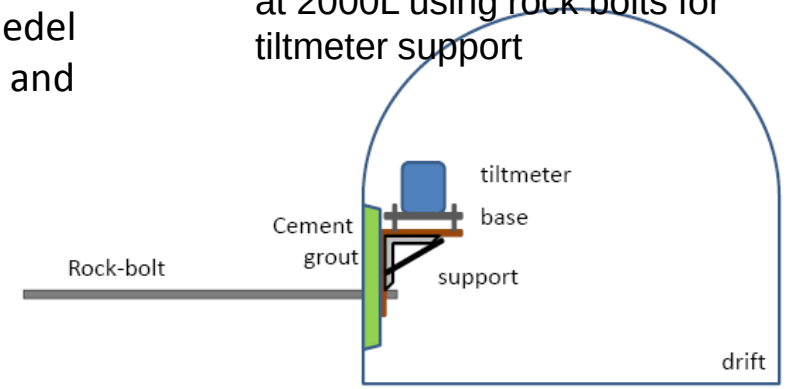


Monitoring Deformation and Acoustic Events



Events with magnitude >0.5 recorded by Friedel et al. between 7100 and 7250 levels

Experimental arrangement at 2000L using rock bolts for tiltmeter support



Deep EcoHydrology – Science Drivers

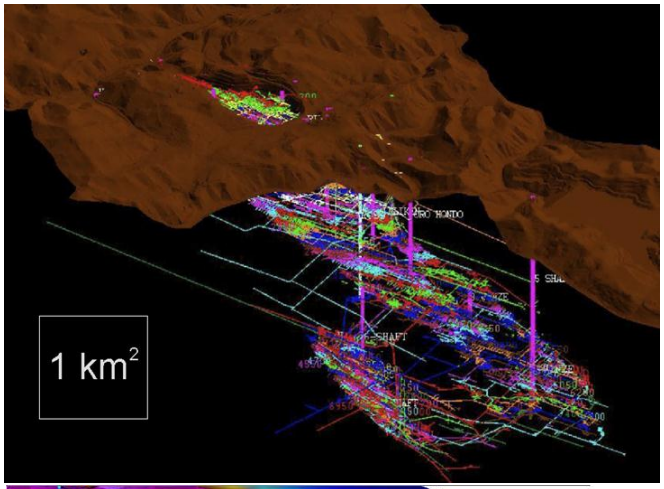
Investigating the interactions between fluids, stress and life

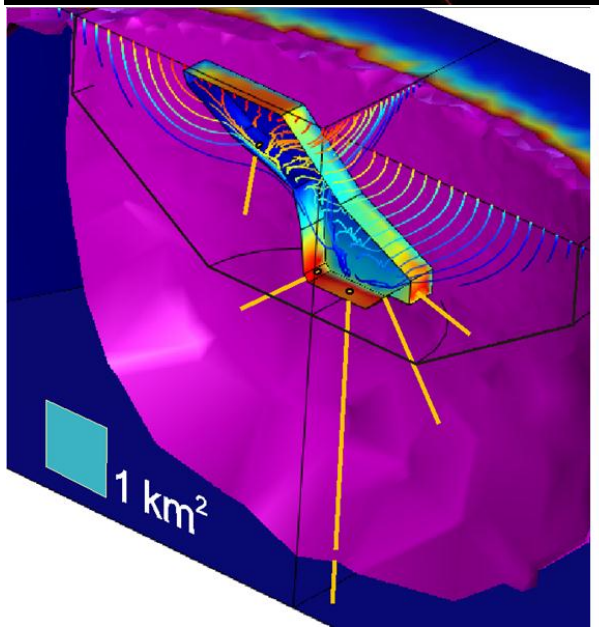
How Deeply and by What Mechanisms Does Life Extend into the Earth?

- Do geomechanical and hydrologic factors control the distribution of life as a function of depth and temperature?
- What patterns in microbial diversity, microbial activity and nutrients are found along this gradient?
- How do state variables (stress, strain, temperature, and pore pressure) and constitutive properties (permeability, porosity, modulus, etc.) vary at nested spatial scales and timescales?

Unique Attributes at DUSEL

- Scale and Duration of Access
  - A window into the deep biosphere from base of photosphere to abiotic fringe zone
- Effect of Changing Habitat
  - Important for understanding ecological response
- Large-scale Tracer Test
  - Huge volumes of rock responding to transients
- Geologic Setting
  - Rock type similar to that underlying all continents





Subsurface Imaging and Sensing

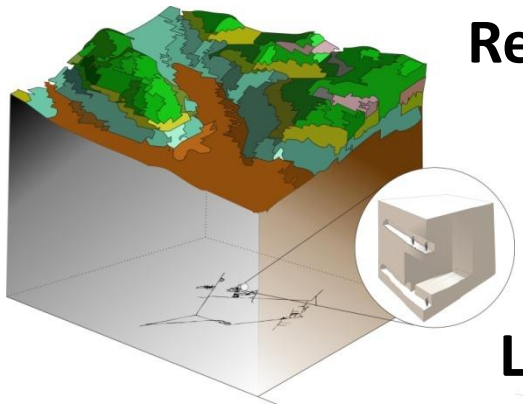
Geoscience Goals

- Constrain source mechanisms
  - Full 3-D coverage
  - Proximal and enveloping measurements
  - Strong coupling
  - Ultra-low-noise environment
- Potential to take seismology from a 10+% to a 1% science

Geoengineering Goals

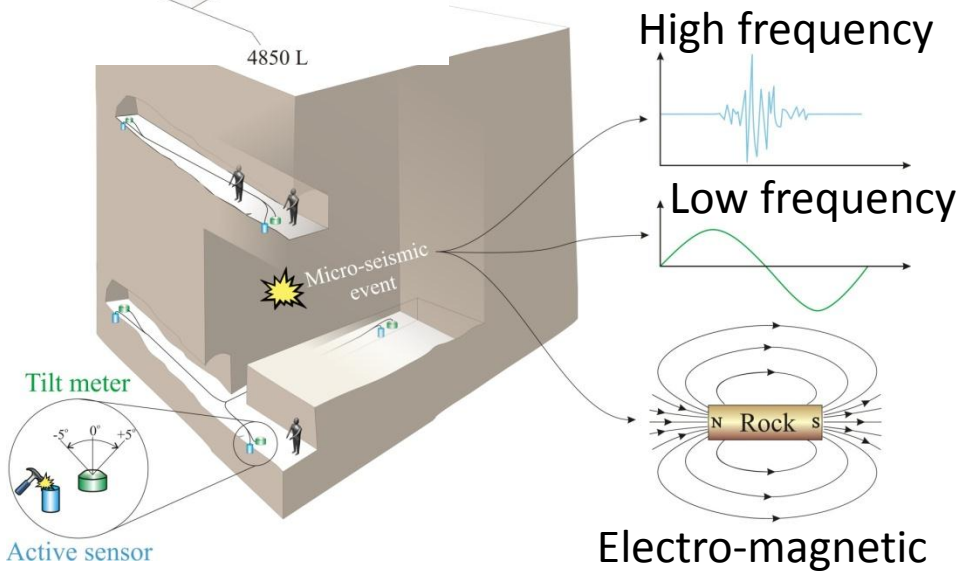
- Condition monitoring of experiments for: stress, energy, deformation, failure modes…….

Measure the Rock State?



Regional Scale

Laboratory Scale



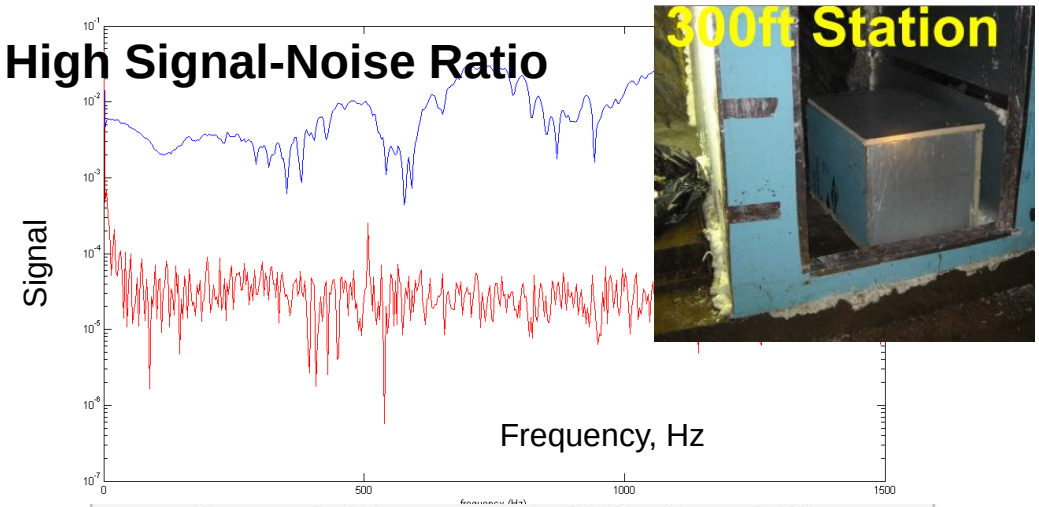
Subsurface Imaging and Sensing [Expt Layout]

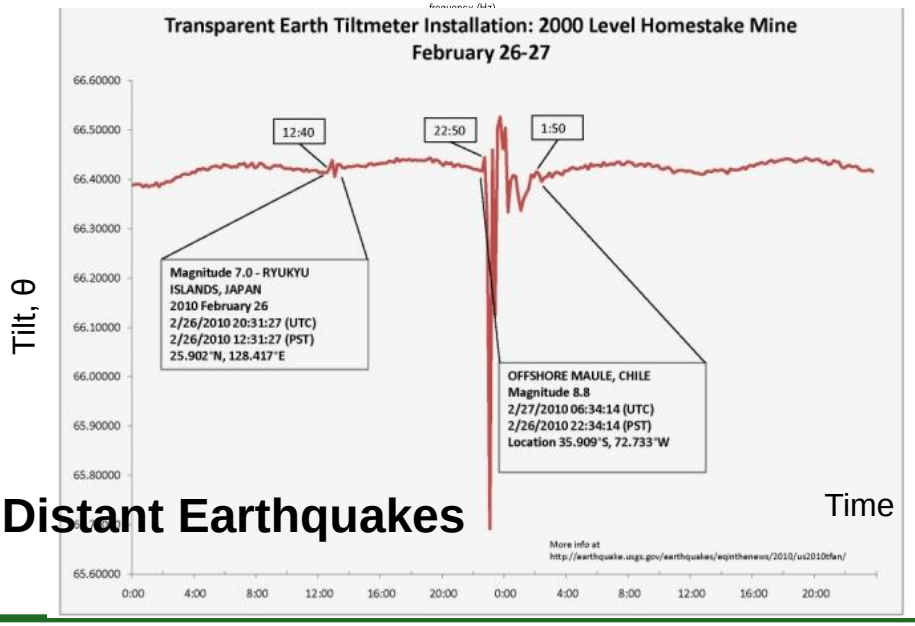
Geoscience Goals

- Constrain source mechanisms
  - Full 3-D coverage
  - Proximal and enveloping measurements
  - Strong coupling
  - Ultra-low-noise environment
- Potential to take seismology from a 10+% to a 1% science
- Gravity waves (DUGL)

Geoengineering Goals

- Condition monitoring of experiments for: stress, energy, deformation, failure modes…….

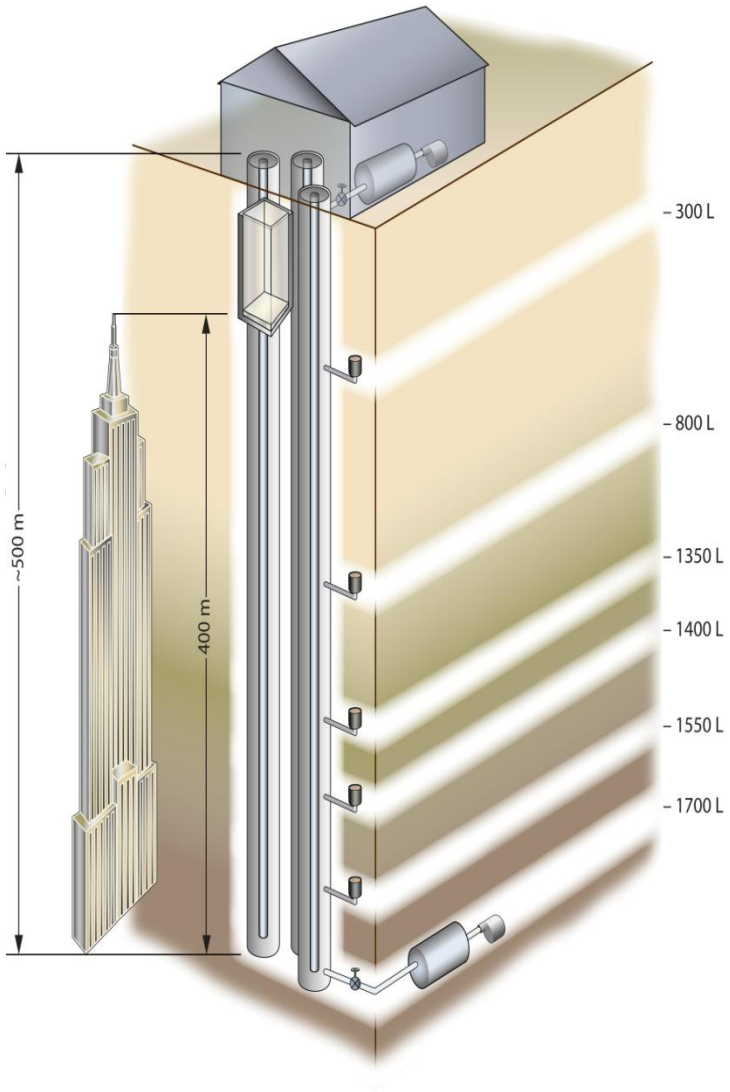




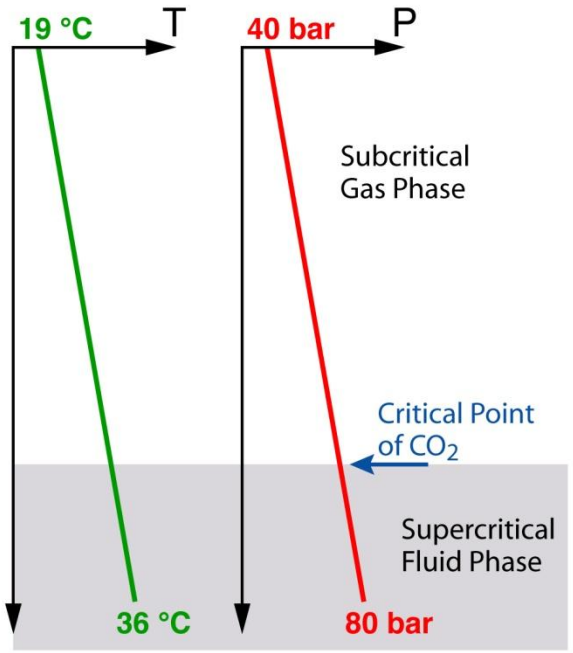
Tilt from Distant Earthquakes

FACILITY-BASED EXPERIMENTS [CO_2/THMCB/FRX]

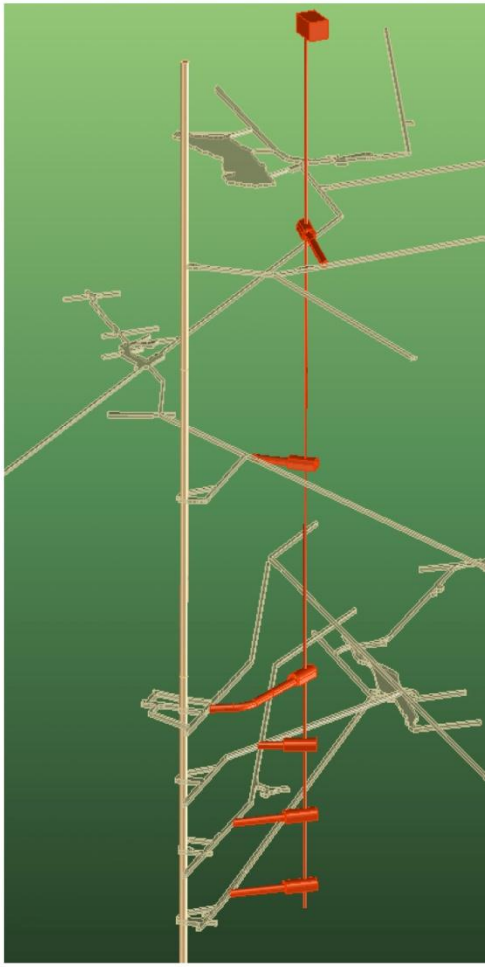
LUCI - Geologic Carbon Storage – Experimental Layout



Conceptual Design for
DUSEL CO2 Laboratory



- Long Pressure vessels filled with sedimentary materials
- Vertical bored raise ~3 m in diameter, 500 m in height
- Access at two or more intermediate drifts



Transport and Reaction Processes Experiment – Science Drivers

Key Scientific Question:

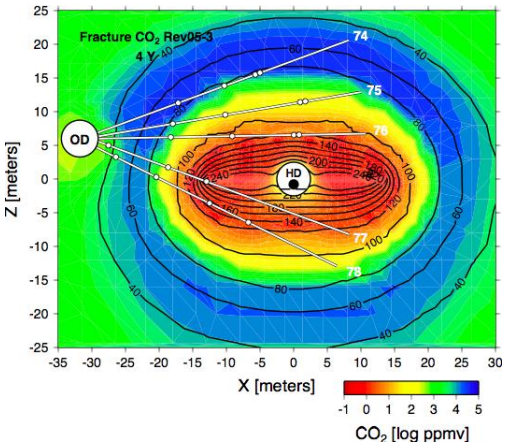
How do mechanical and transport properties evolve and influence fluid chemistry and microbial populations?

Intellectual Merit:

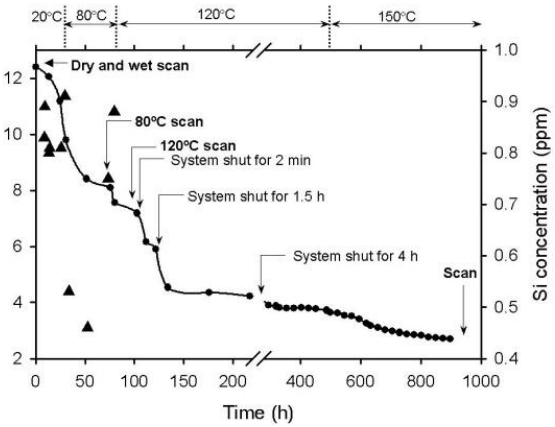
Advance understanding of fault zones, geothermal reservoirs, magmatic-hydrothermal systems, ore mineralization, radioactive waste, other.

Process interactions and feedbacks are scale-dependent, complex and often enigmatic - requiring large-scale well-controlled *in-situ* experiments to understand response.

Modeled concentration of chemical species around heater



Permeability-drop in fracture with chemical reaction and collapse



Transport and Reaction Processes Experiment – Experimental Layout

Experimental Approach

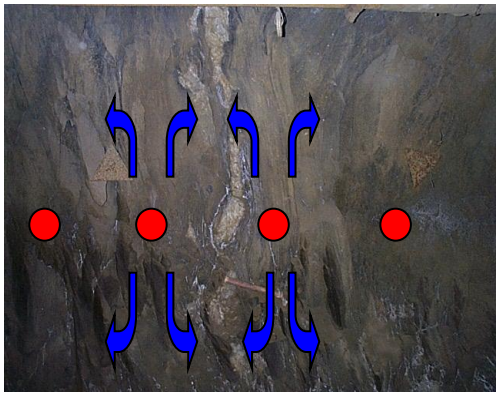
a.) characterize site, b.) install infrastructure
c.) heat d.) monitor e.) core samples
d.) excavate (*mine back*) and describe.

- **Hydrothermal Convection**
- **Biological Gradient Experiment**
- **Effective Reaction Rates**
- **Geothermal Stimulation Experiment**

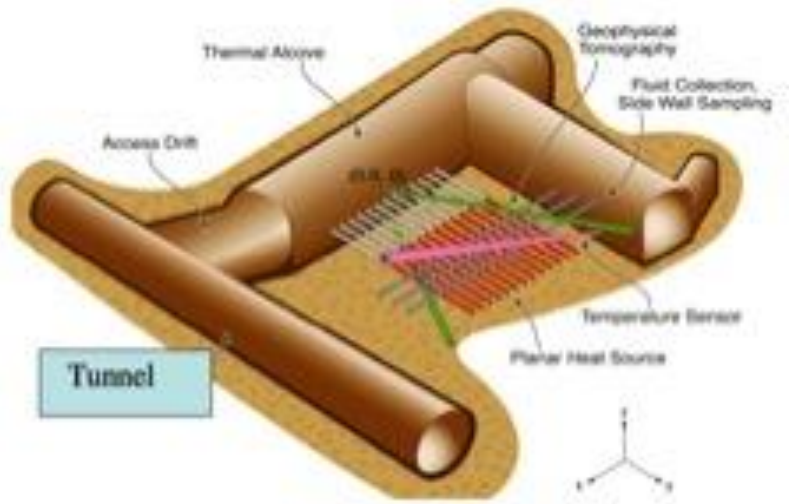
THMCB S4 Tasks

- Select candidate rock mass and tunnel complexes based on geological, mineralogical, hydrological and fracture data
- Preliminary design, refined through the following steps of characterization and pre-test modeling:
  - Laboratory experiments
  - Modeling
  - Evaluation of new technologies
- Development of **WBS**
- Working group meetings to refine design and costs

Ellison Formation & Heaters



Experimental Layout

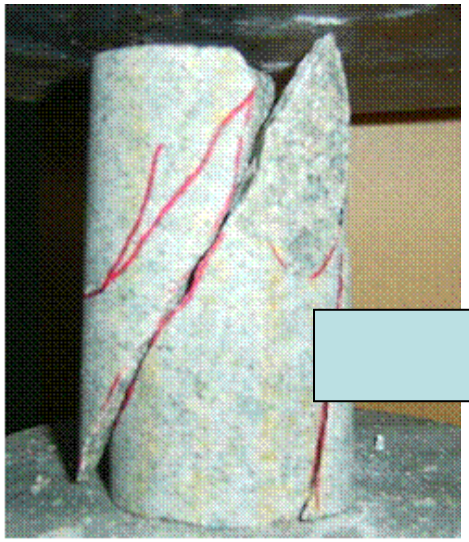


Faulting Processes Experiment – Science Drivers

Hypothesis: Faulting processes change with scale, so small laboratory experiments are incomplete representations of real faults. Larger experiments are needed to advance understanding of faulting.

Faulting Processes

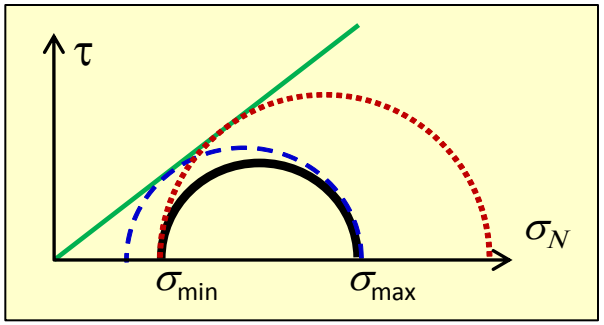
Propagation in intact rock
Gouge development
Friction laws
Fault reactivation
Corresponding seismic response
Fluid effects
Microbial interactions
Sealing and healing
many others….

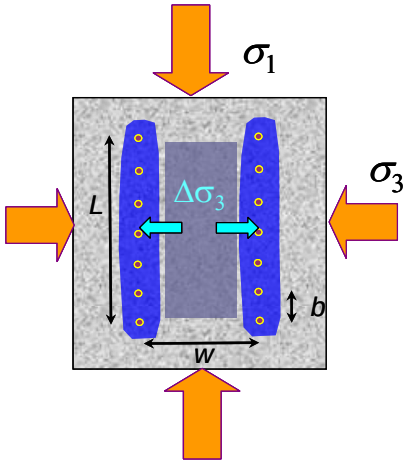


Faulting Processes Experiment – Experimental Layout

Approach

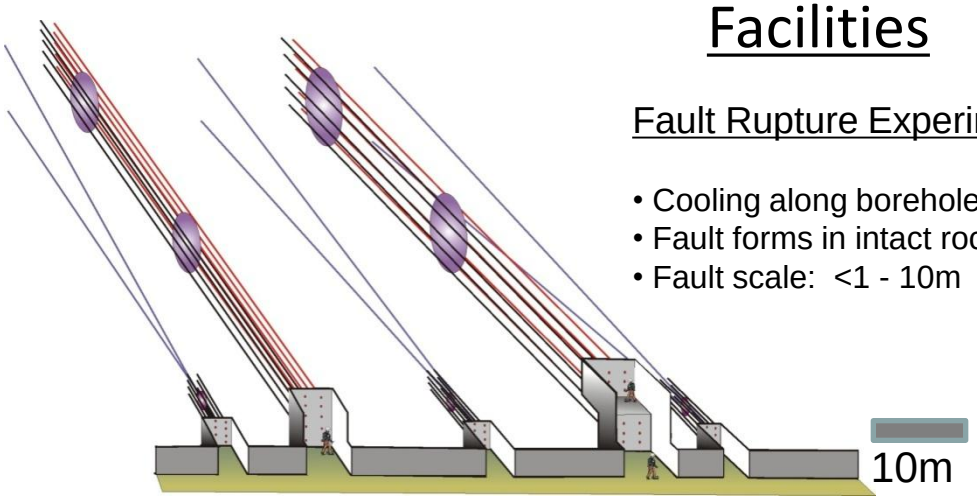
- Faulting by either increasing or decreasing stress





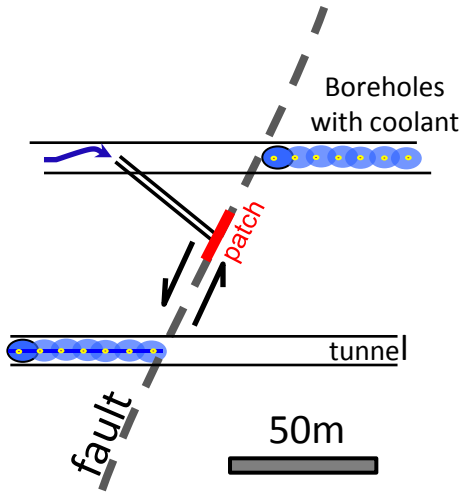
Cooling two rows of boreholes to change stress→ cause faulting

Facilities



Fault Rupture Experiment

- Cooling along borehole arrays
- Fault forms in intact rock
- Fault scale: <1 - 10m



Slip Propagation Experiment

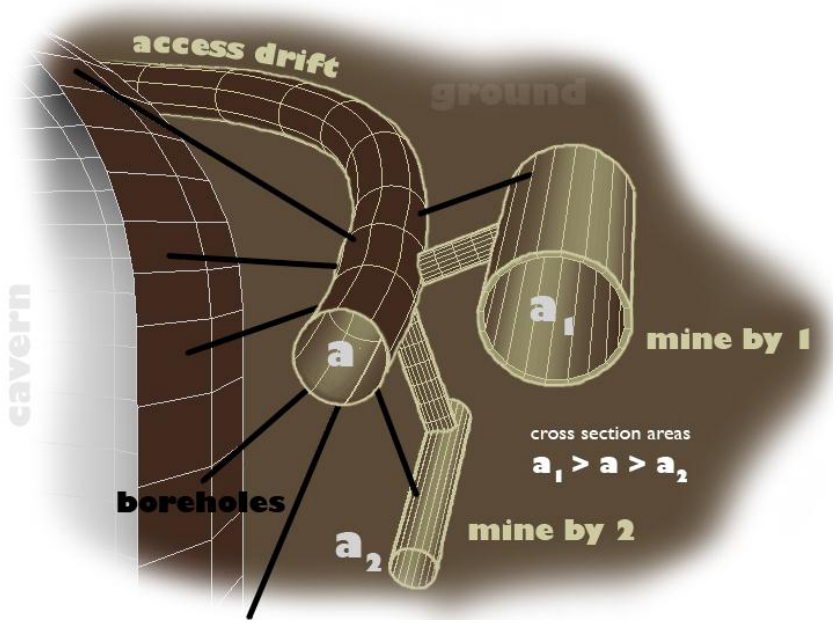
- Cooling on 2 levels to increase shear stress.
- Inject water to initiate slip.
- Slip nucleates on patch
- Patch grows until unstable
- Critical patch size ~ 1m, so need block 10-100m

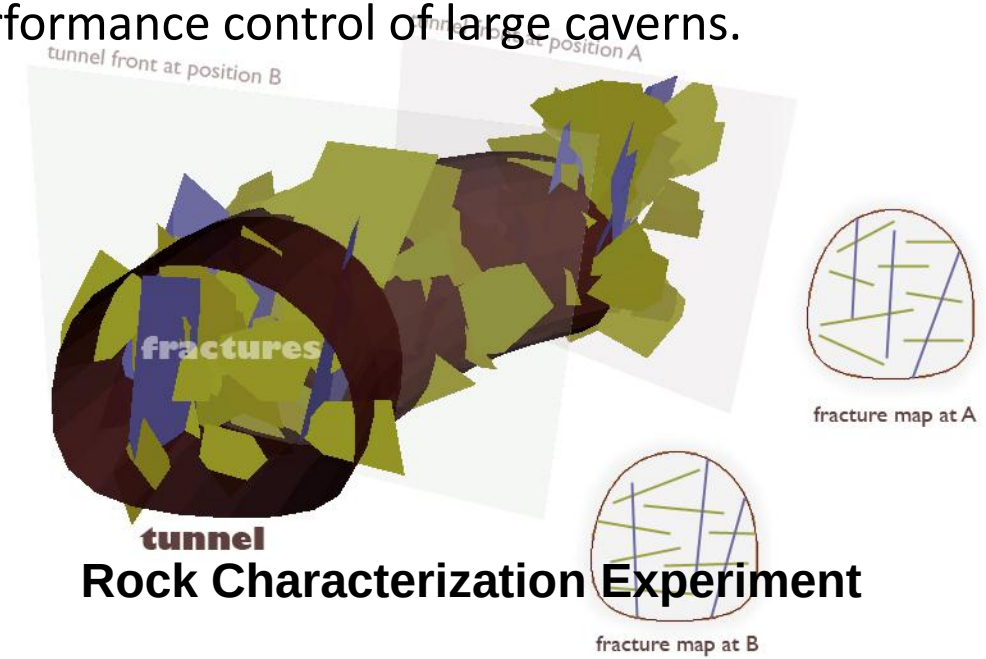
CAVITY EXPERIMENTS

Cavern Design and Instrumentation – Experimental Layout

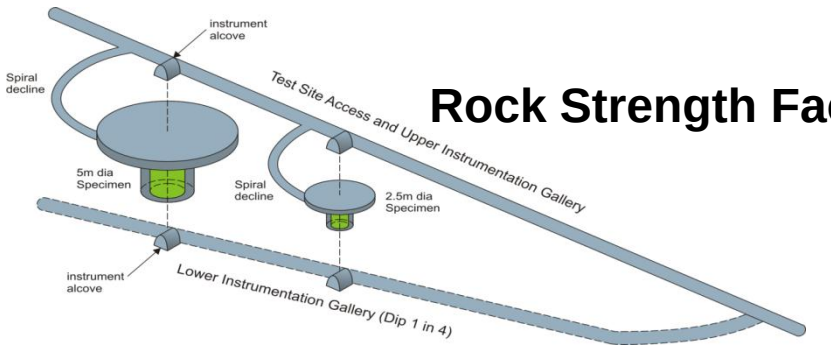
Vision: Determine spatial- and temporal-scale behavior of rock masses for design, construction and long-term performance control of large caverns.

Sensor Array and Mine-By Tunnels



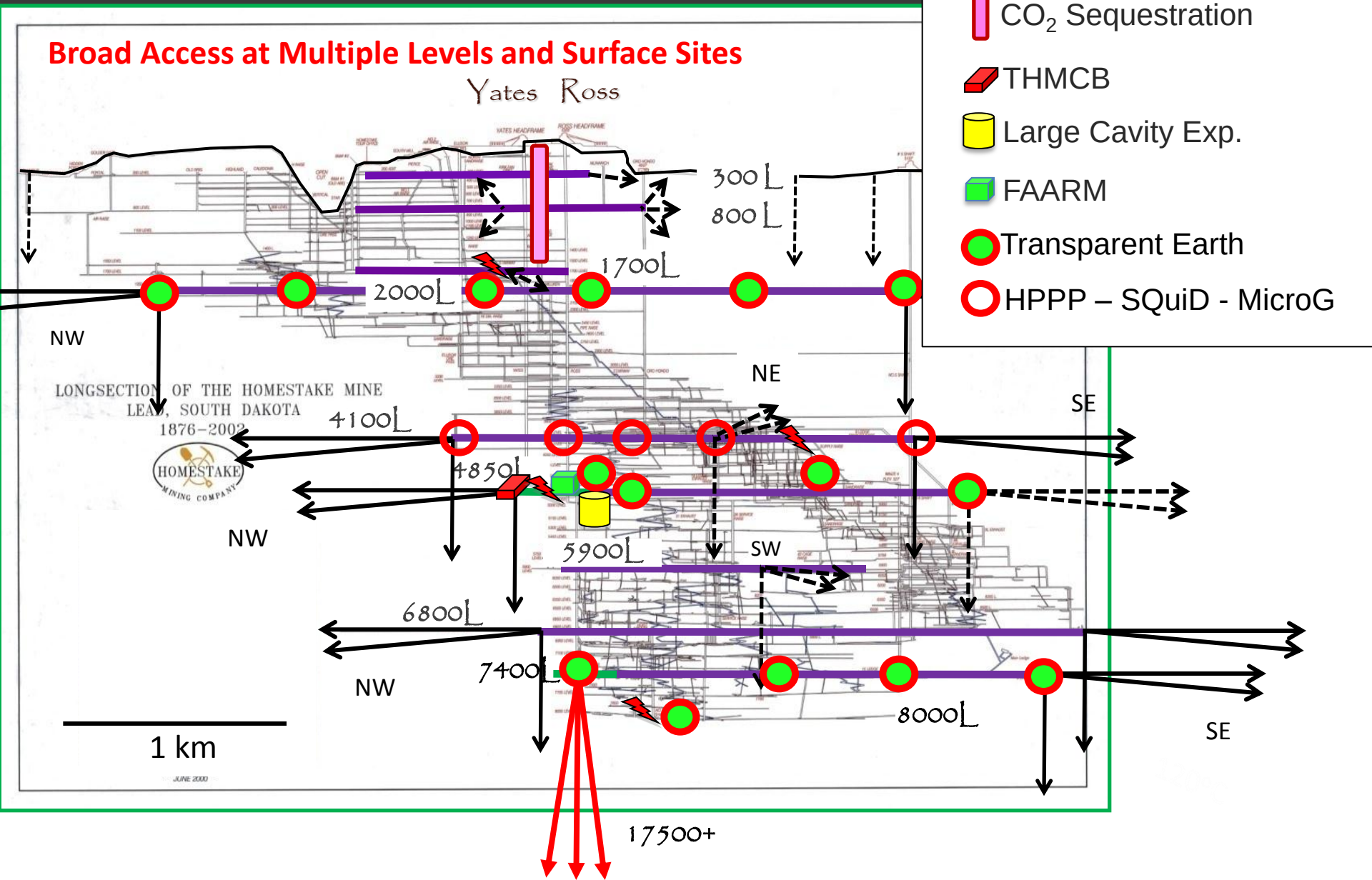


Rock Characterization Experiment



Rock Strength Facility

Experimental Layout



Current Status?

Funded Experiments

- 8 total S-3
- 3 Experiments Ongoing
  - GEOX
  - Seismic Imaging
  - Ecohydrology

Underground Research Laboratory Initiative (Joe Wang)

- Canadian SUMIT Initiative
- Paradigm shift/return to active mines
- ……