Science@DUSEL: Biology, Geoscience & Engineering

[dusel.org]

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DEDC and DuRA

FermiLab, September 3, 2010

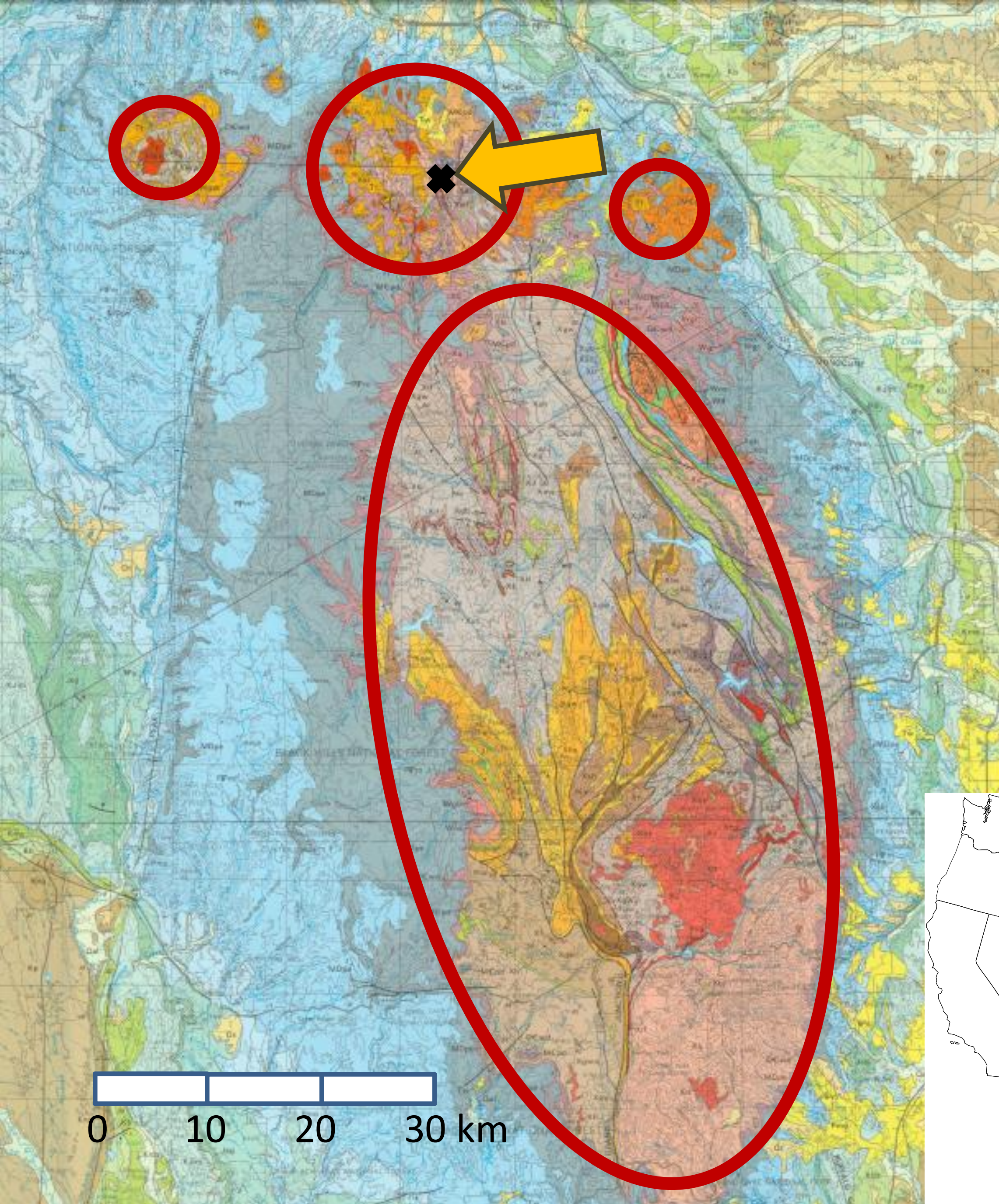
[dusel.org; Deep Science, Sadoulet, B. et al., 2007]

Proposed Science@DUSEL

- DUSEL not as just a low background facility
- Scope of Biology-Geoscience-Engineering (BGE) Programs
  - Distributed Experiments [FiberOptic/EcoHydrol/Drilling/Transp. Earth]
  - Facility-Based Experiments [CO2/THMCB/Frx]
  - Cavity Experiments
- Facility layout with experiments
- Concluding remarks

DUSEL Homestake

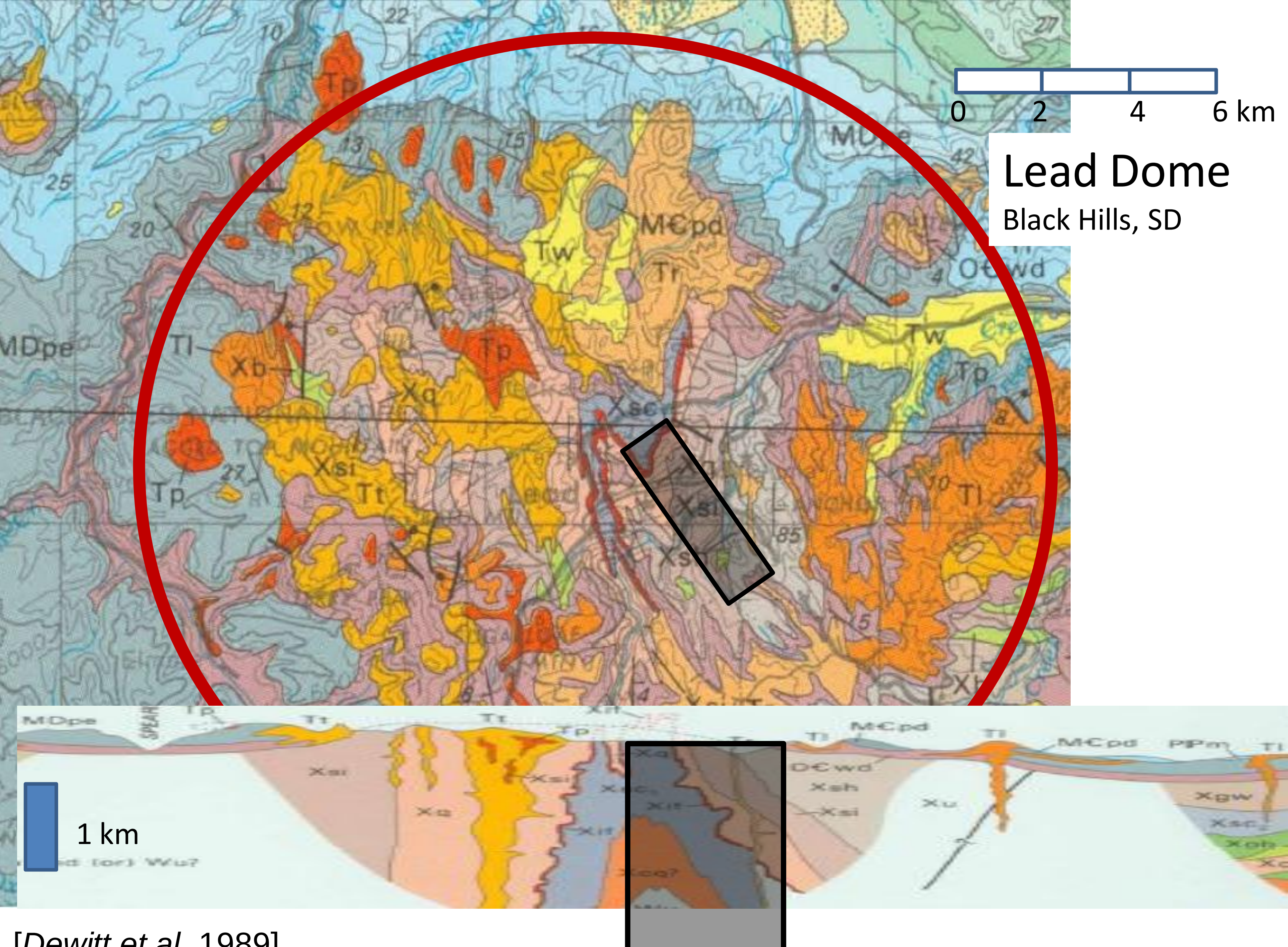
Geologic and Hydrogeologic Setting



[*Dewitt et al.* 1989]

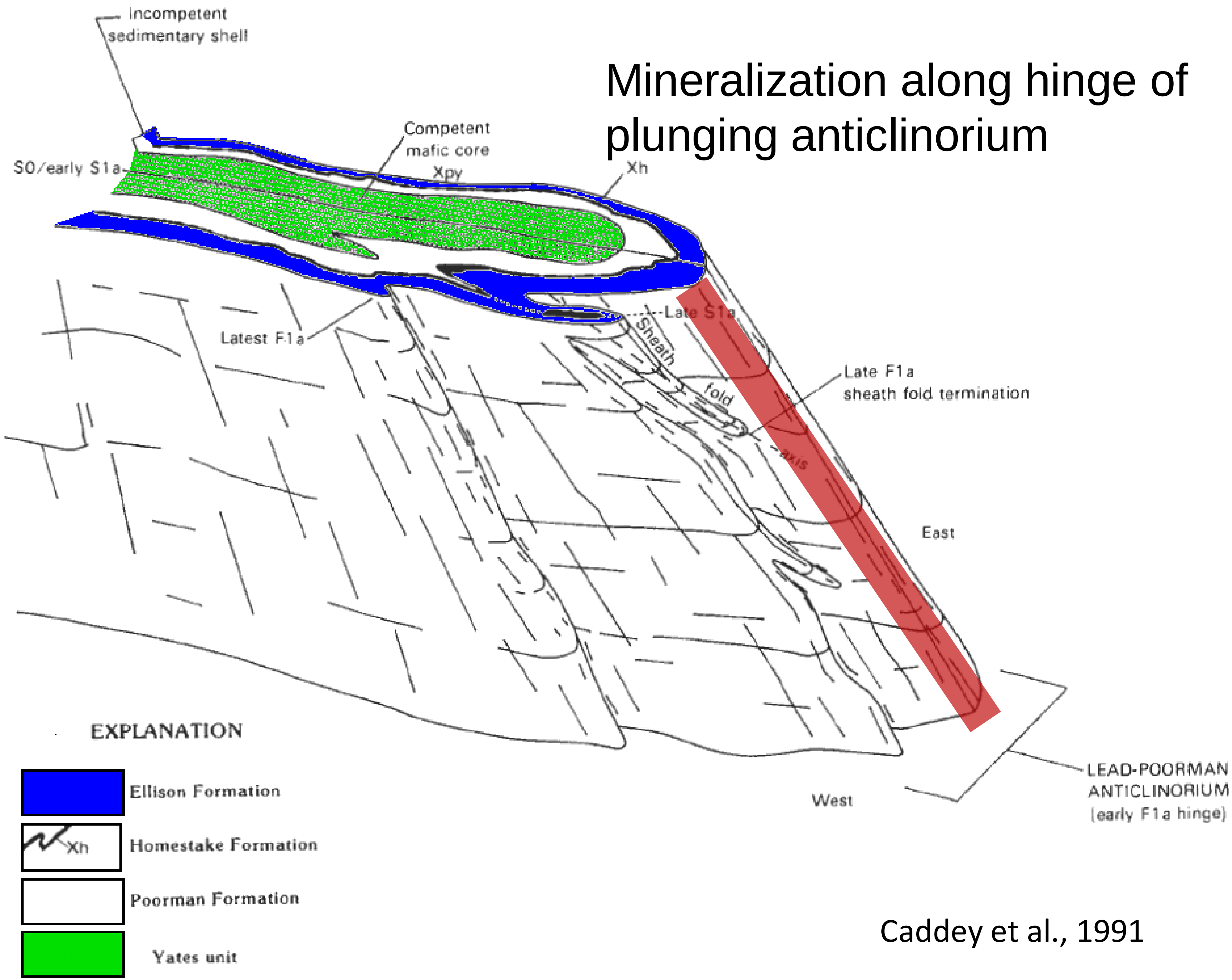
Lead Dome

Black Hills, SD



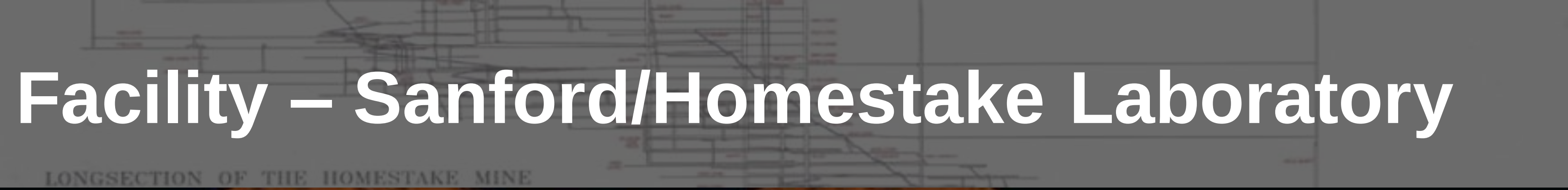
[*Dewitt et al.* 1989]

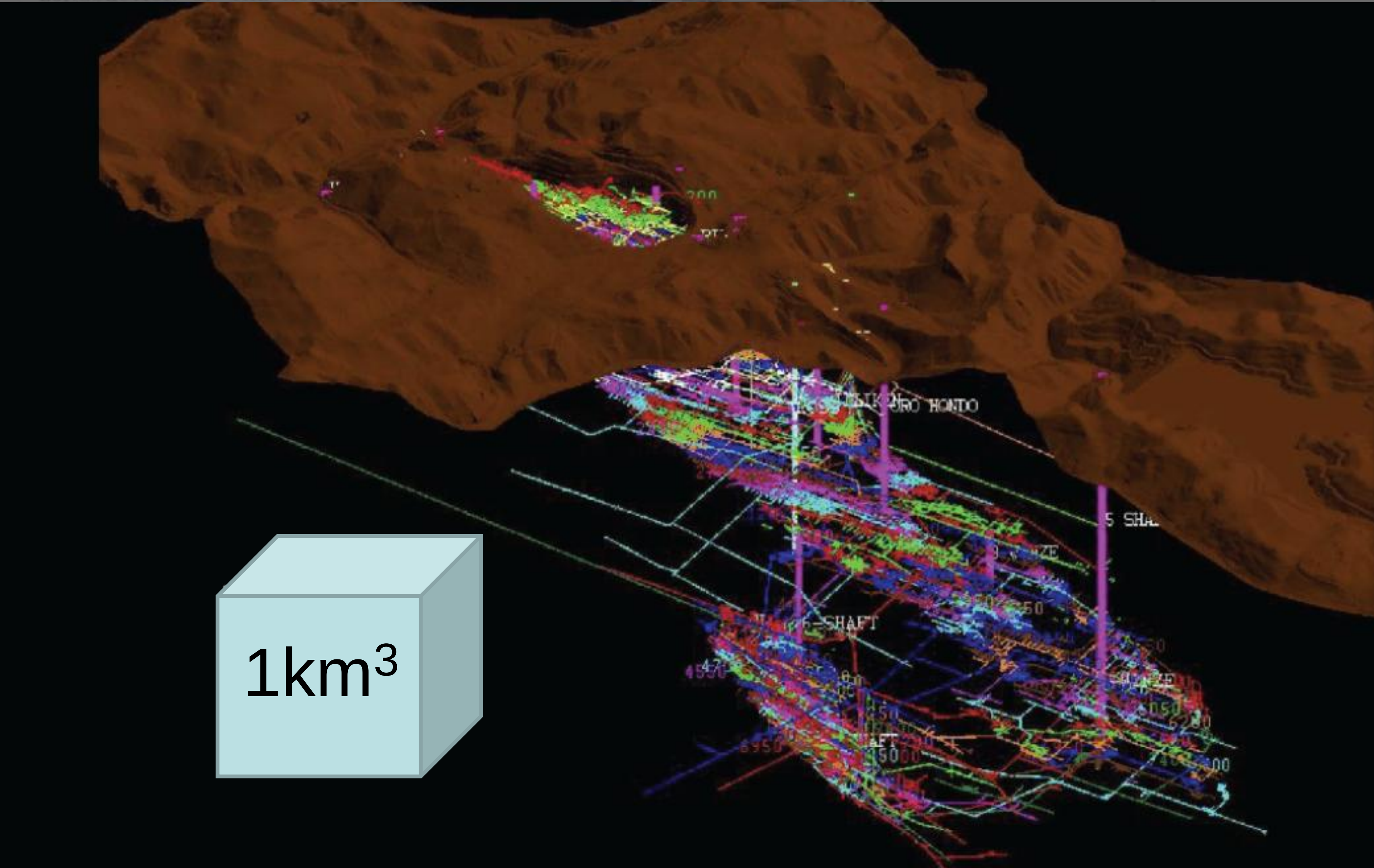
Mineralization along hinge of plunging anticlinorium



Caddey et al., 1991

Facility – Sanford/Homestake Laboratory





Open Pit
Lead, SD
Workings
Tailings Pond
1 km
Image © 2009 DigitalGlobe
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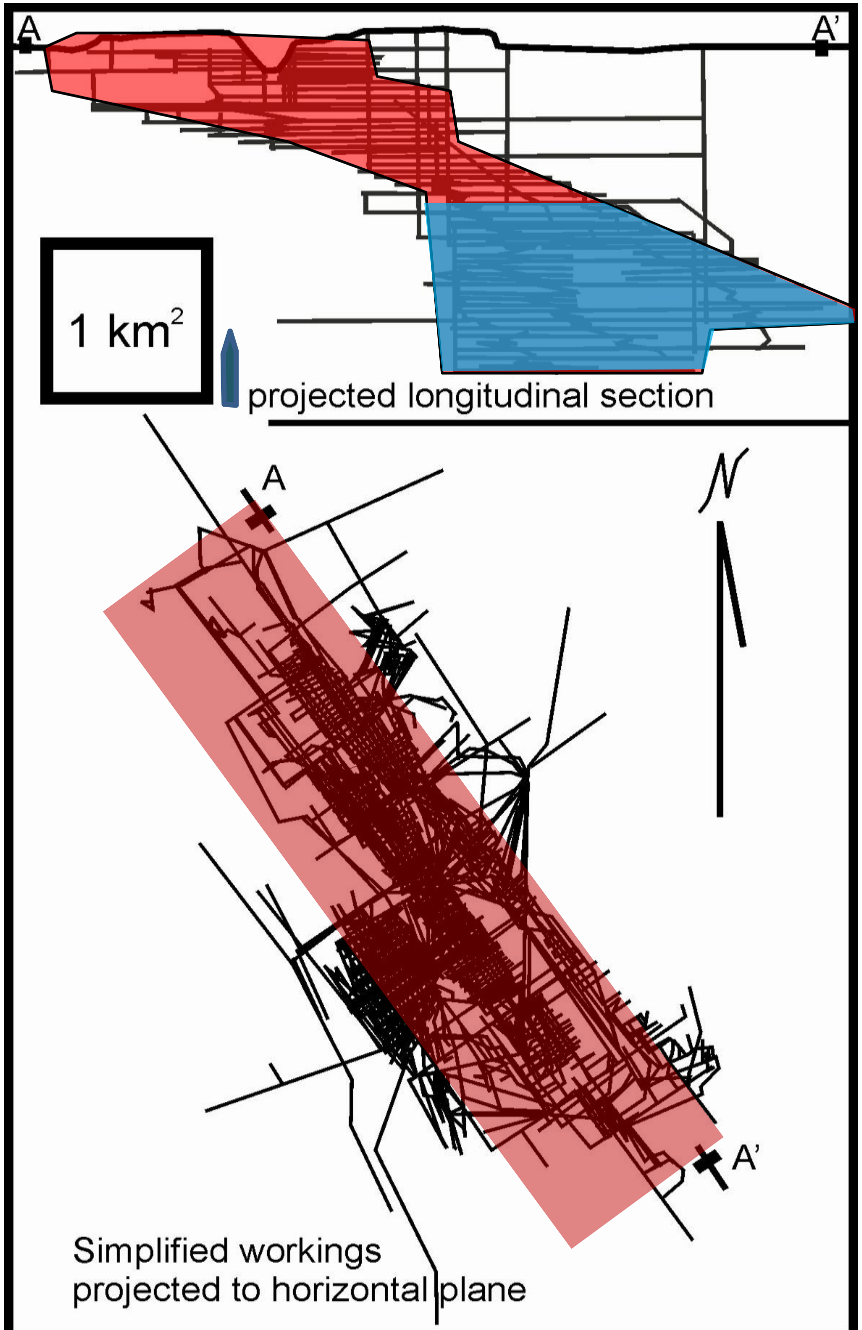
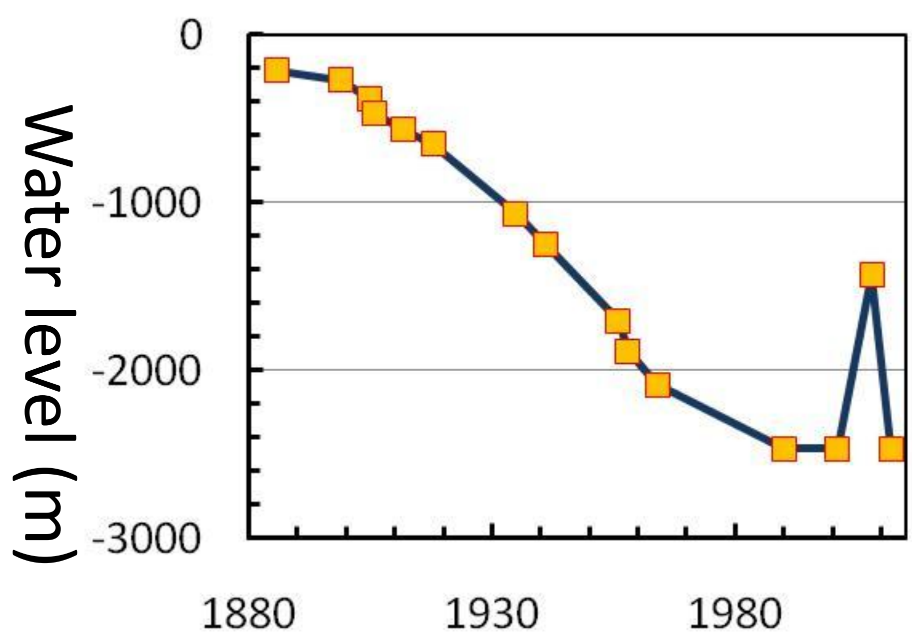
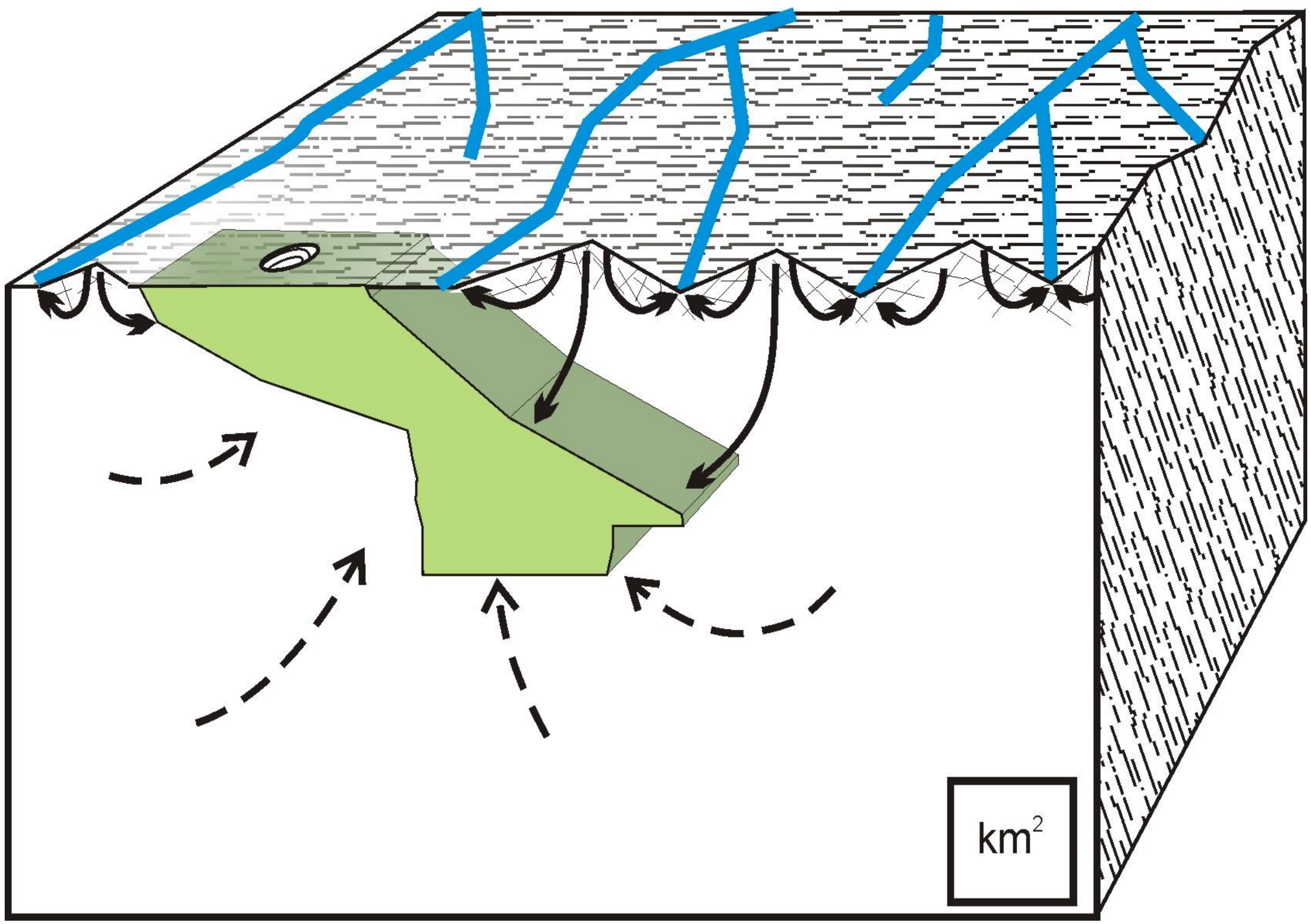


Geometry and History

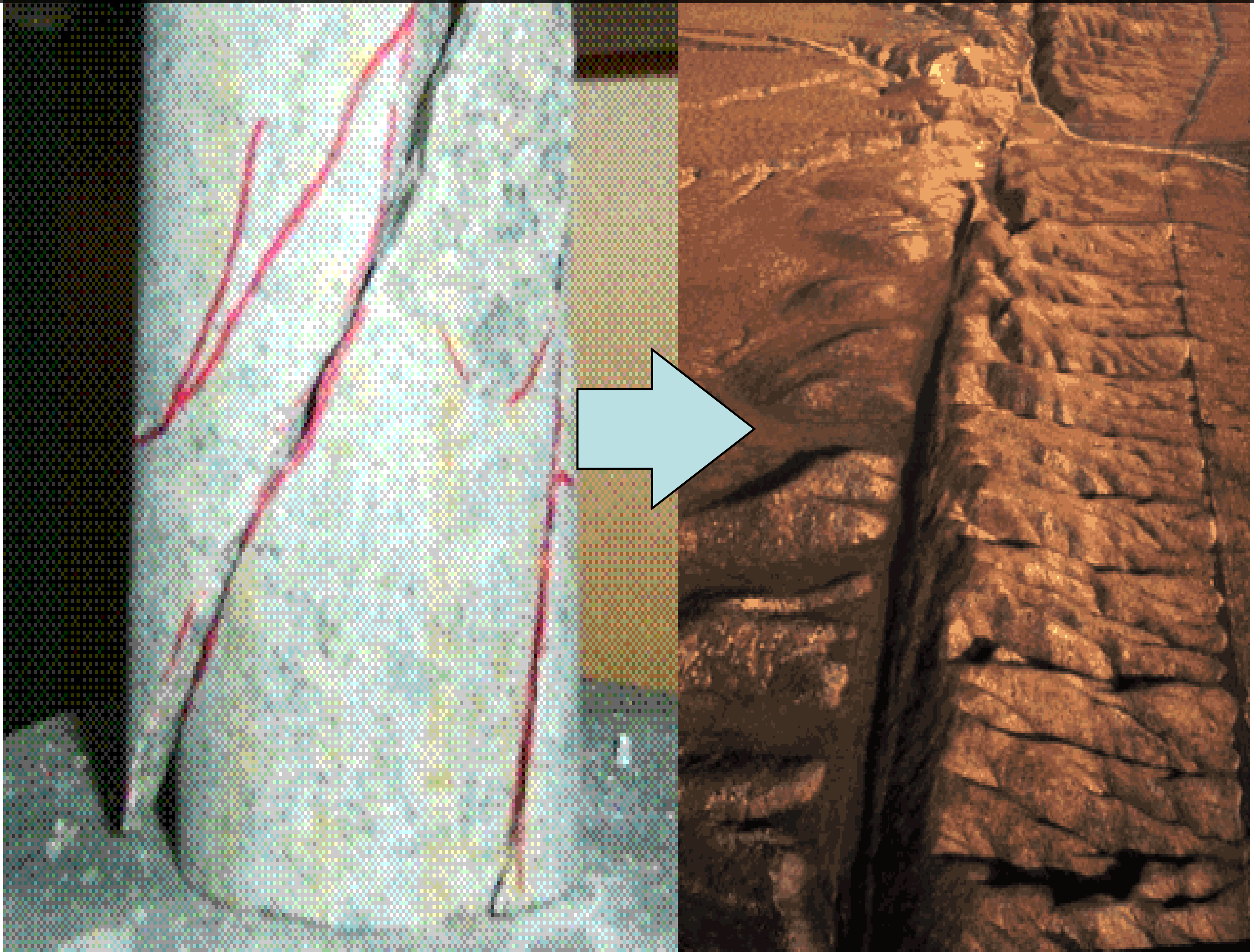
1. Mining → downward tunneling, 100 years until 2002
2. Flooding→mine fills with water, 1 km deep by 2008
3. Draining→mine dewatered by 2012



Hydrogeologic Conceptual Model



Role of Scale Effects in Deformation and Transport



Evolution of DUSEL and Its 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

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

2010: S-4 Science awards completed

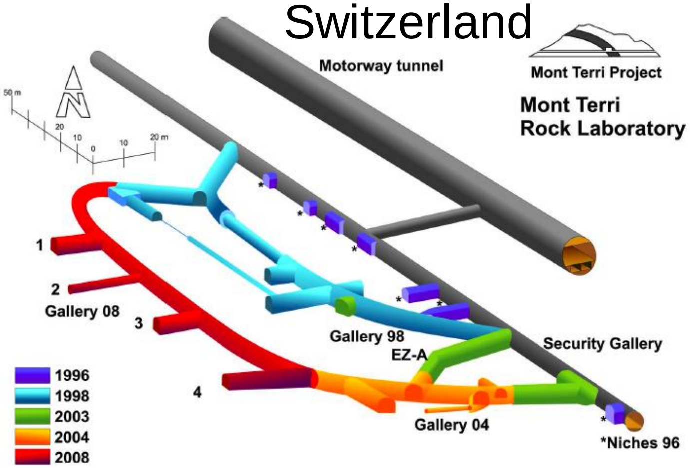
2010: DEDC transitions to DuRA

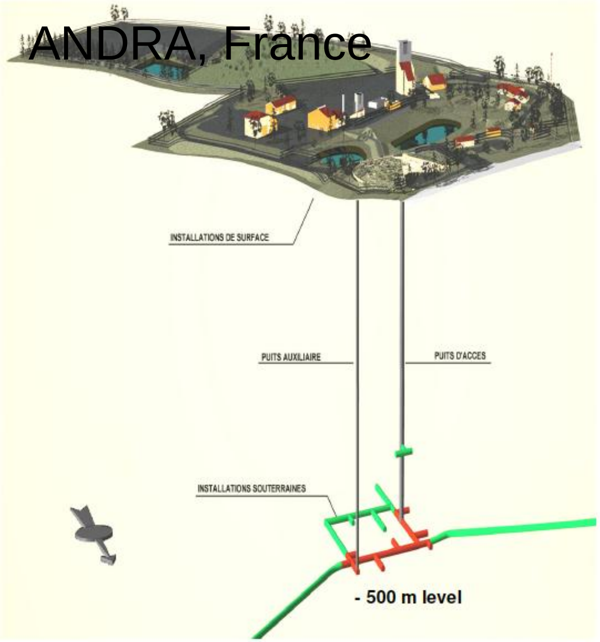
2011: MREFC to National Science Board

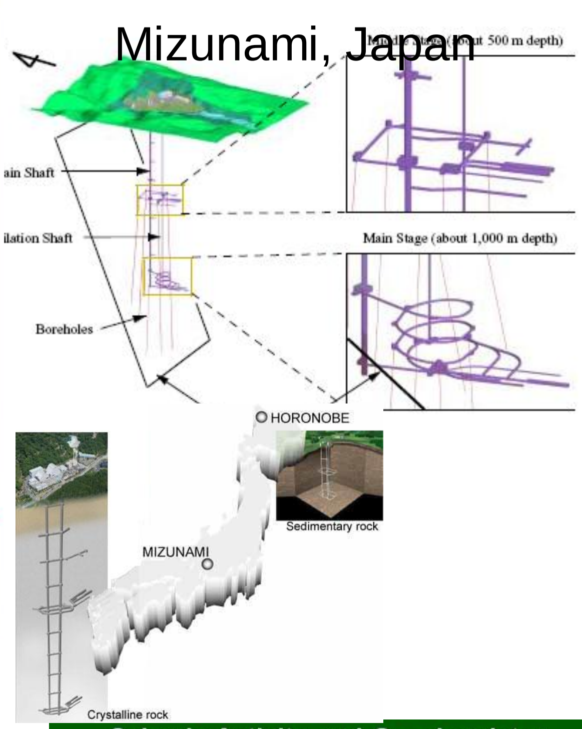
2013+: Initial experimental activities begin

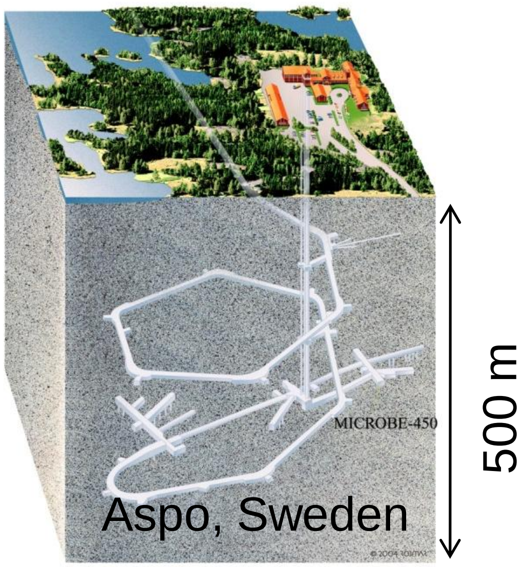
Locations of Deep Continental Subsurface Microbial Investigations

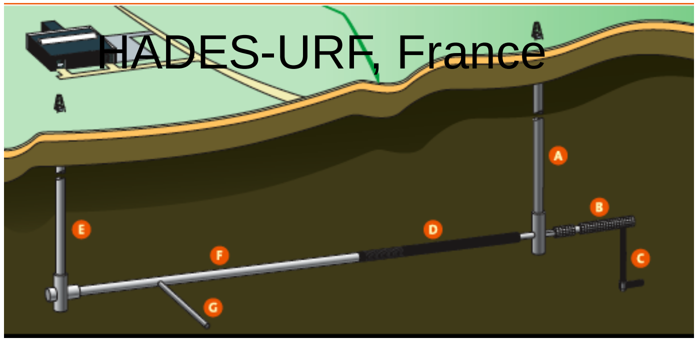
Other Underground BioGeoEng Facilities

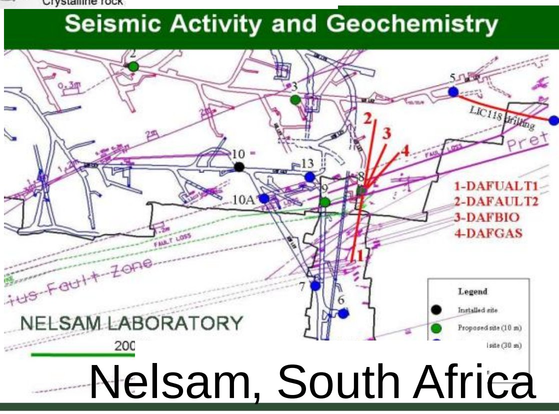




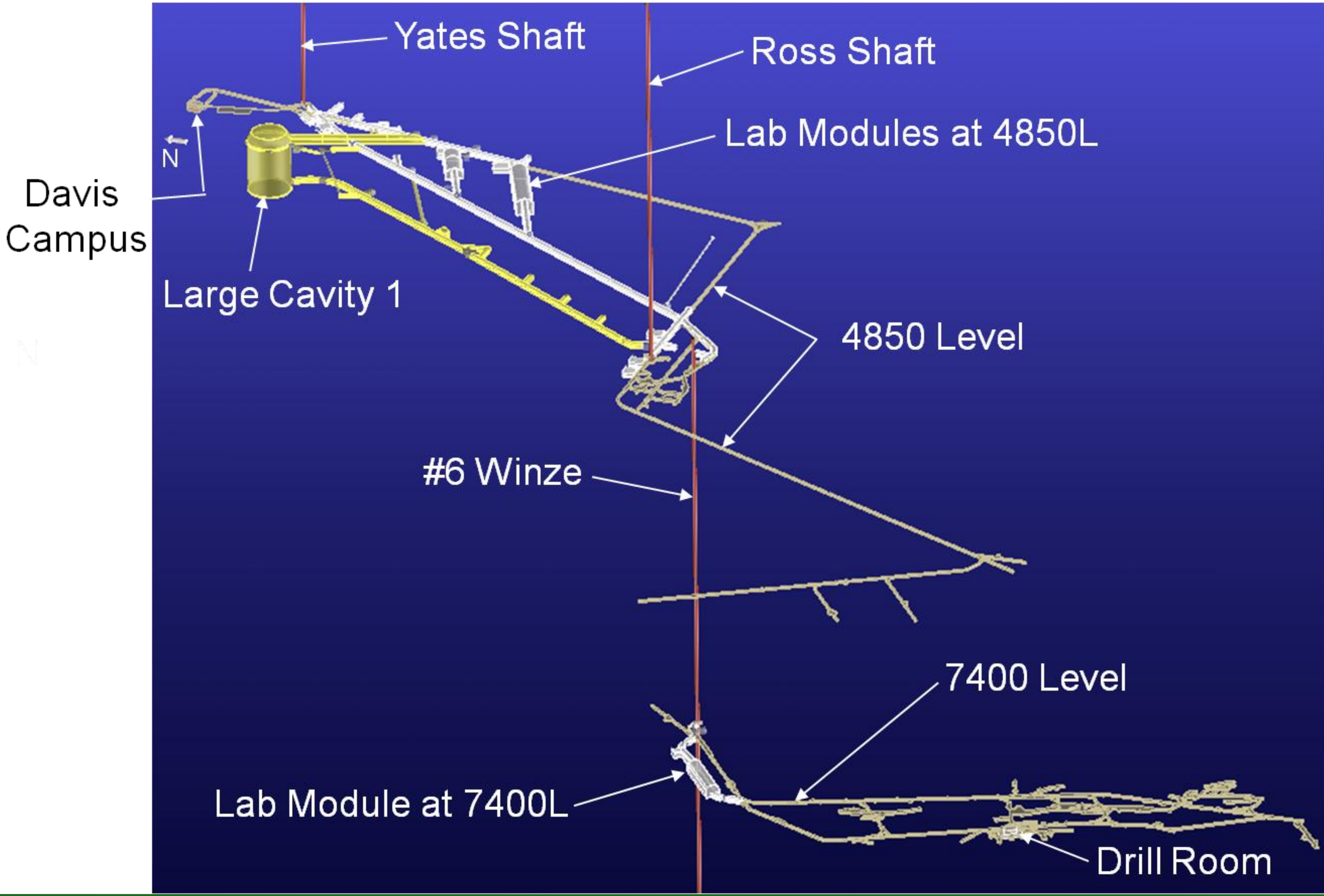






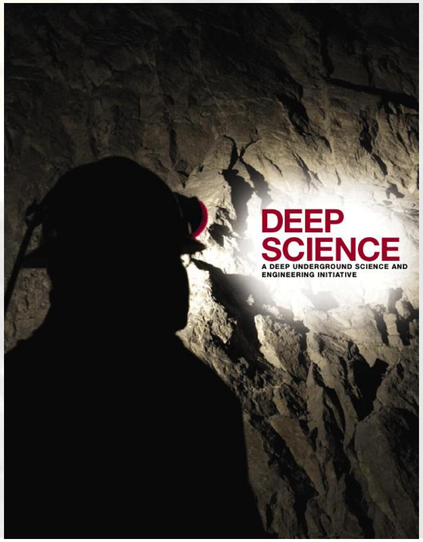


DUSEL Underground Facility



Biology, Geosciences, Engineering – 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	Peters (Princeton); Oldenberg/Dobson(LBNL) + 6 others	**[CMMI+CBET]**
CMMI Coupled THMCB Processes	Sonnenthal (LBNL) + 6 others	**[CMMI+GEO]**
S4 Faulting Processes	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™

LONGSECTION OF THE HOMESTAKE MINE

Geoscience Goals

- How do rock masses deform as a function of spatial scale over long times?
- How does the static deformation field measured by strain sensors relate to microseismicity?
- How are the deformation field and fracture flow coupled?

Geoengineering Goals

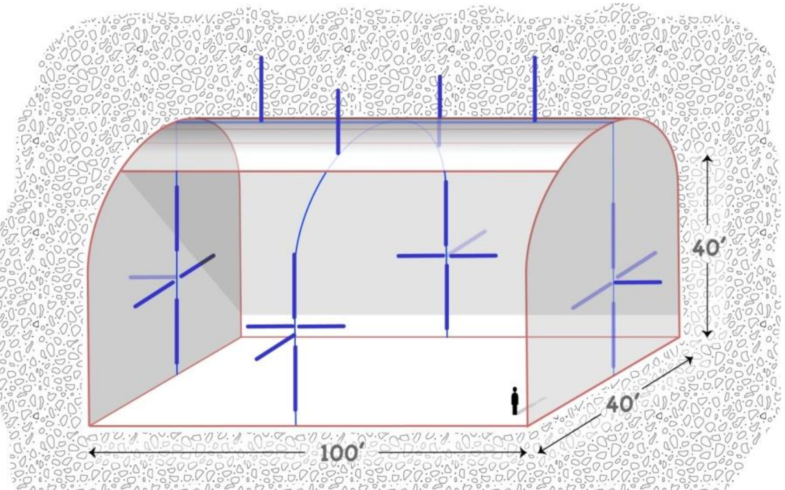
- Large cavity engineering
- General mine monitoring, and safety – How is the mine "breathing?

Technology Goals

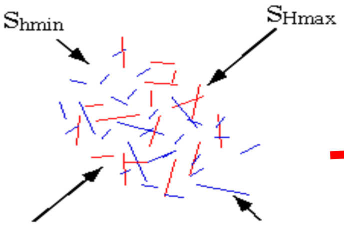
- Determine rock properties that control rock deformation over multiple scales of length and time
- Advance the technology of characterizing rock deformation
- Perform long-term (decadal) structural health monitoring (SHM) of DUSEL.
- Integrate deformation sensors with other physical and chemical fiber-optic sensors into a laboratory-wide environmental and safety monitoring system

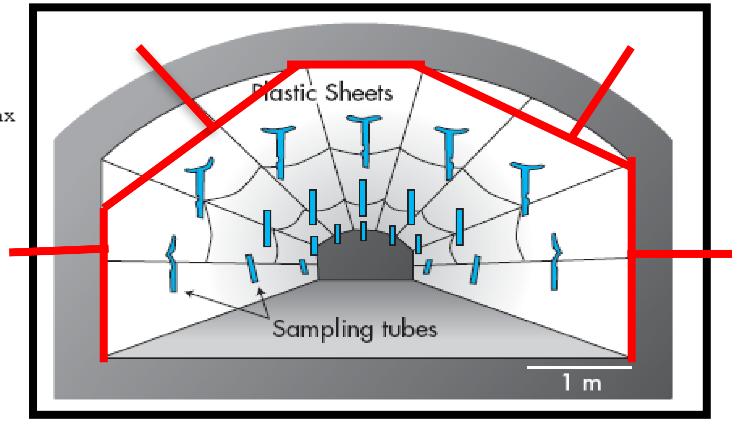
GEOX™ -Experimental Layout

Large Scale Deformability

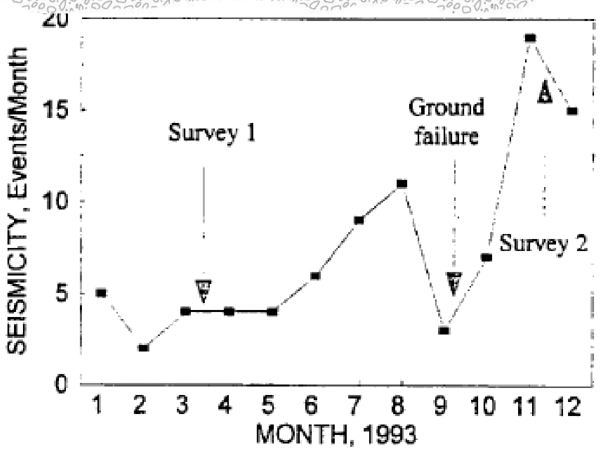


Linking Deformability and Permeability



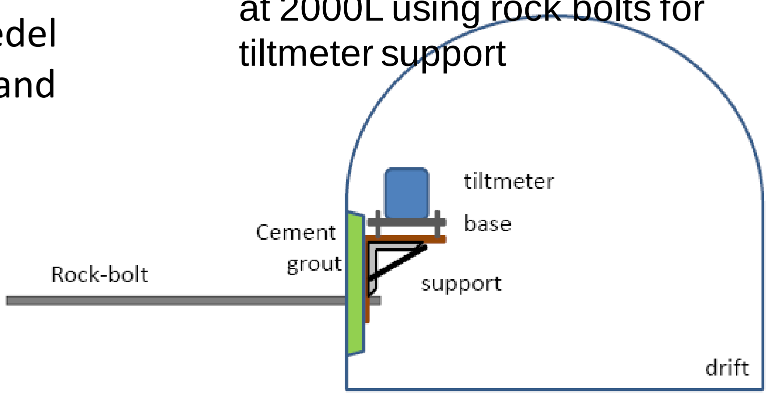


Monitoring Deformation and Acoustic Events



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



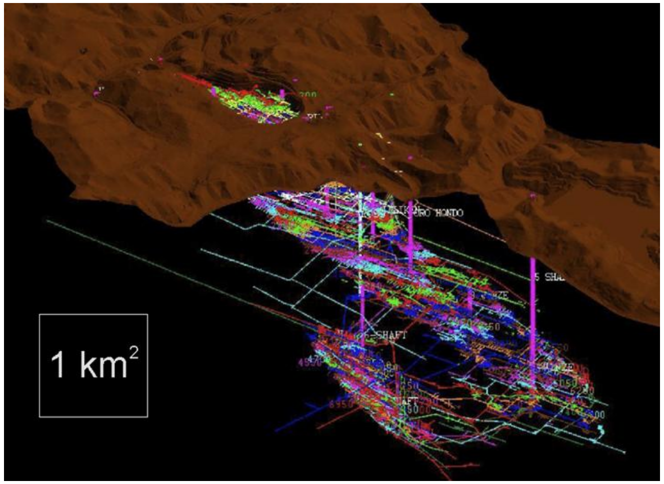
Deep EcoHydrology – Science Drivers
Investigating the interactions between fluids, stress and life

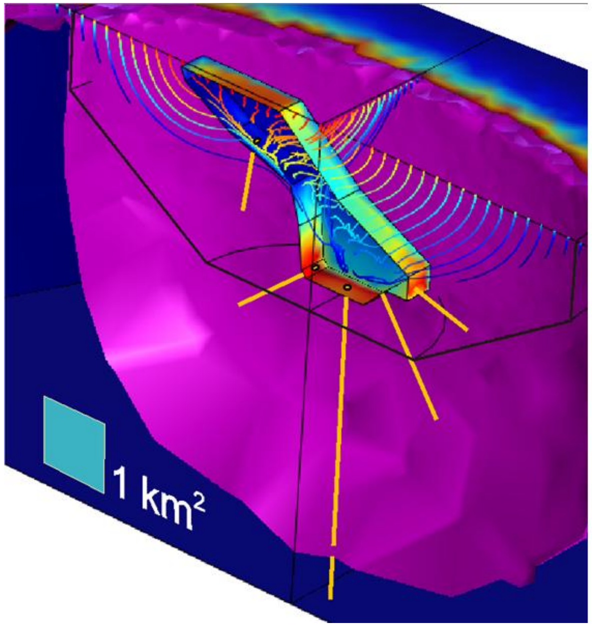
How Deeply and by What Mechanisms Does Life Extend into the Earth?

- 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

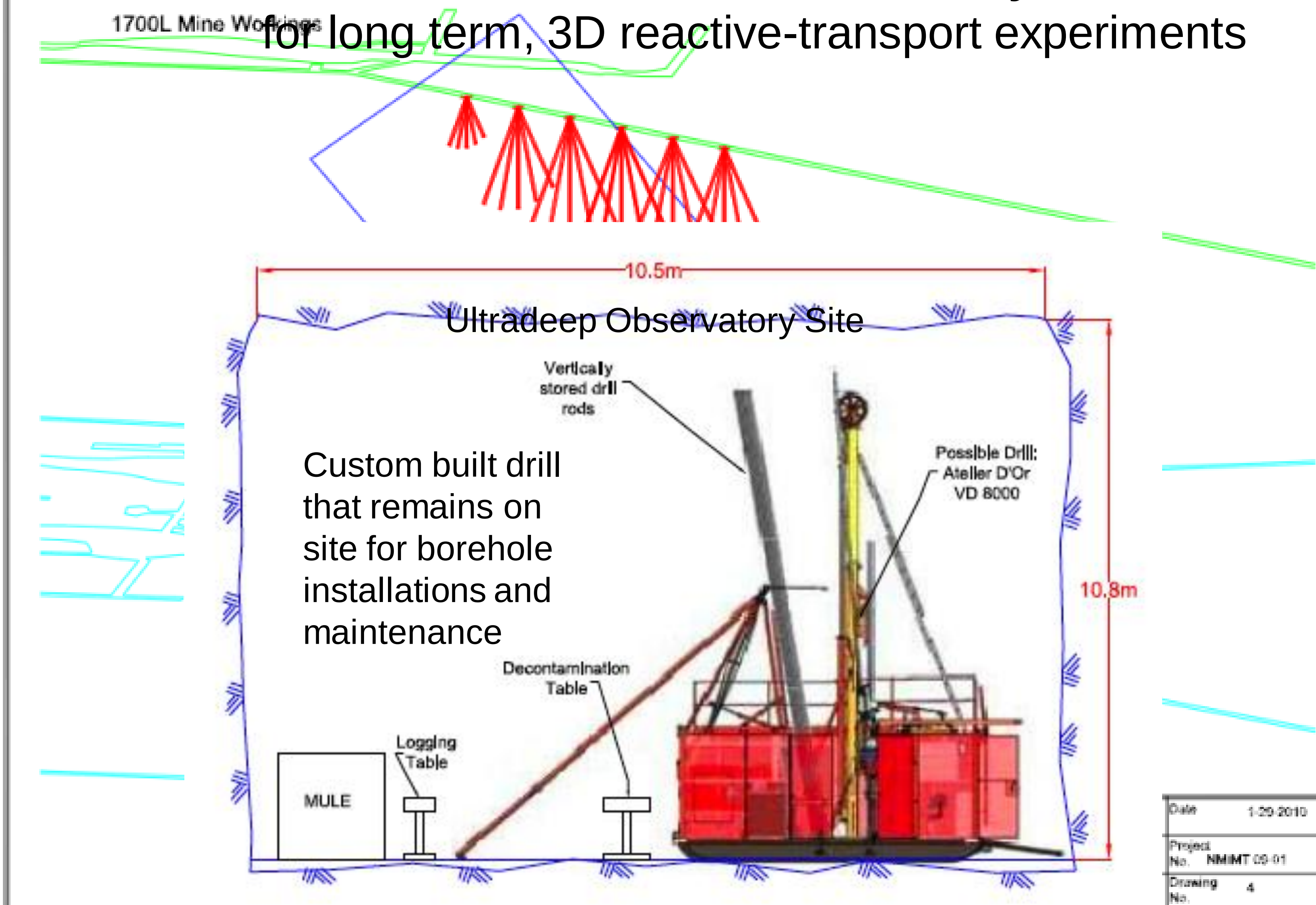
- Scale and Duration of Access
  - A window into the deep biosphere from base of photosphere to abiotic fringe zone
- Effect of Changing Habitat
  - Important for understanding ecological response
- Large-scale Tracer Test
  - Huge volumes of rock responding to transients
- Geologic Setting
  - Rock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



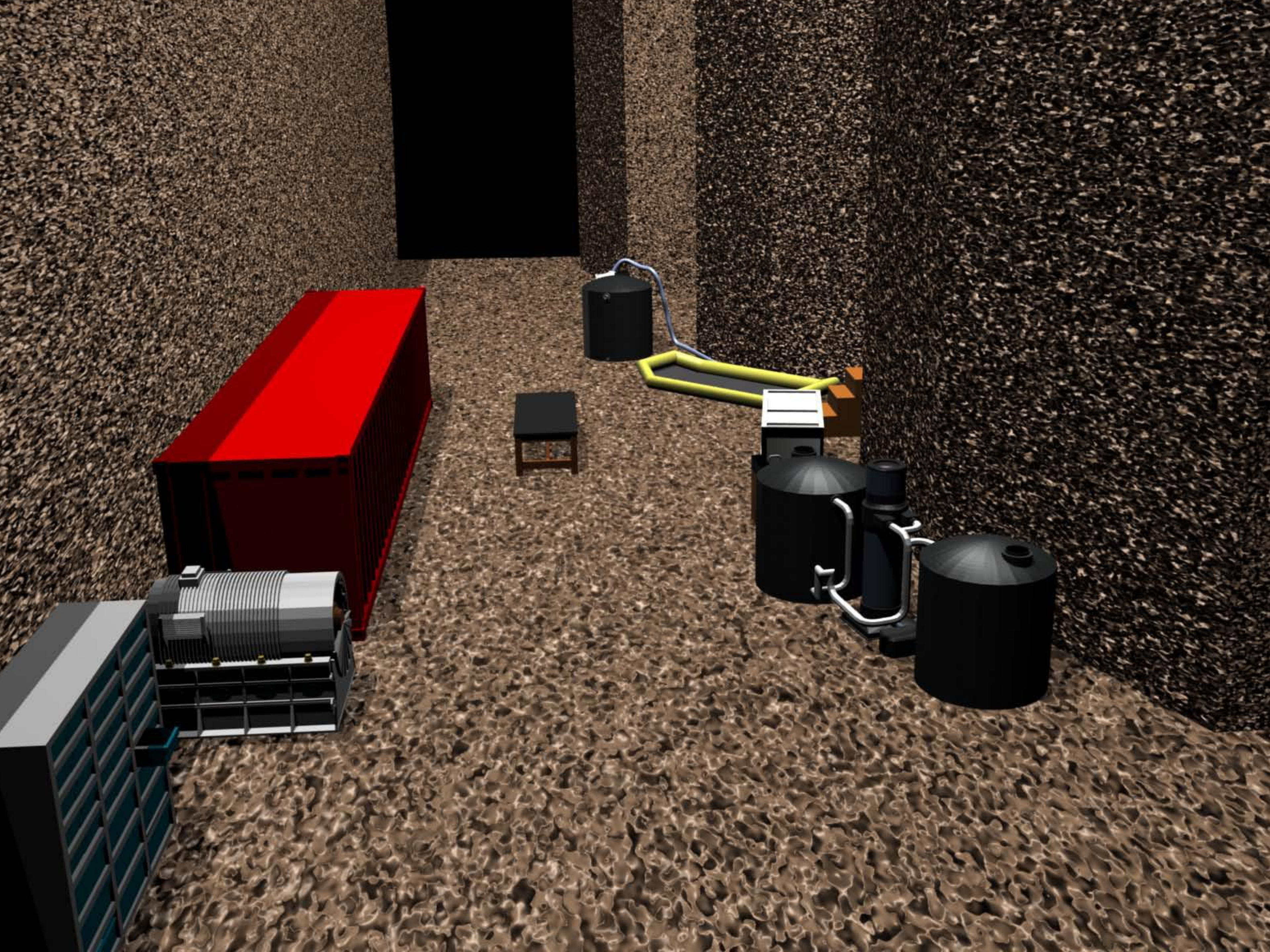


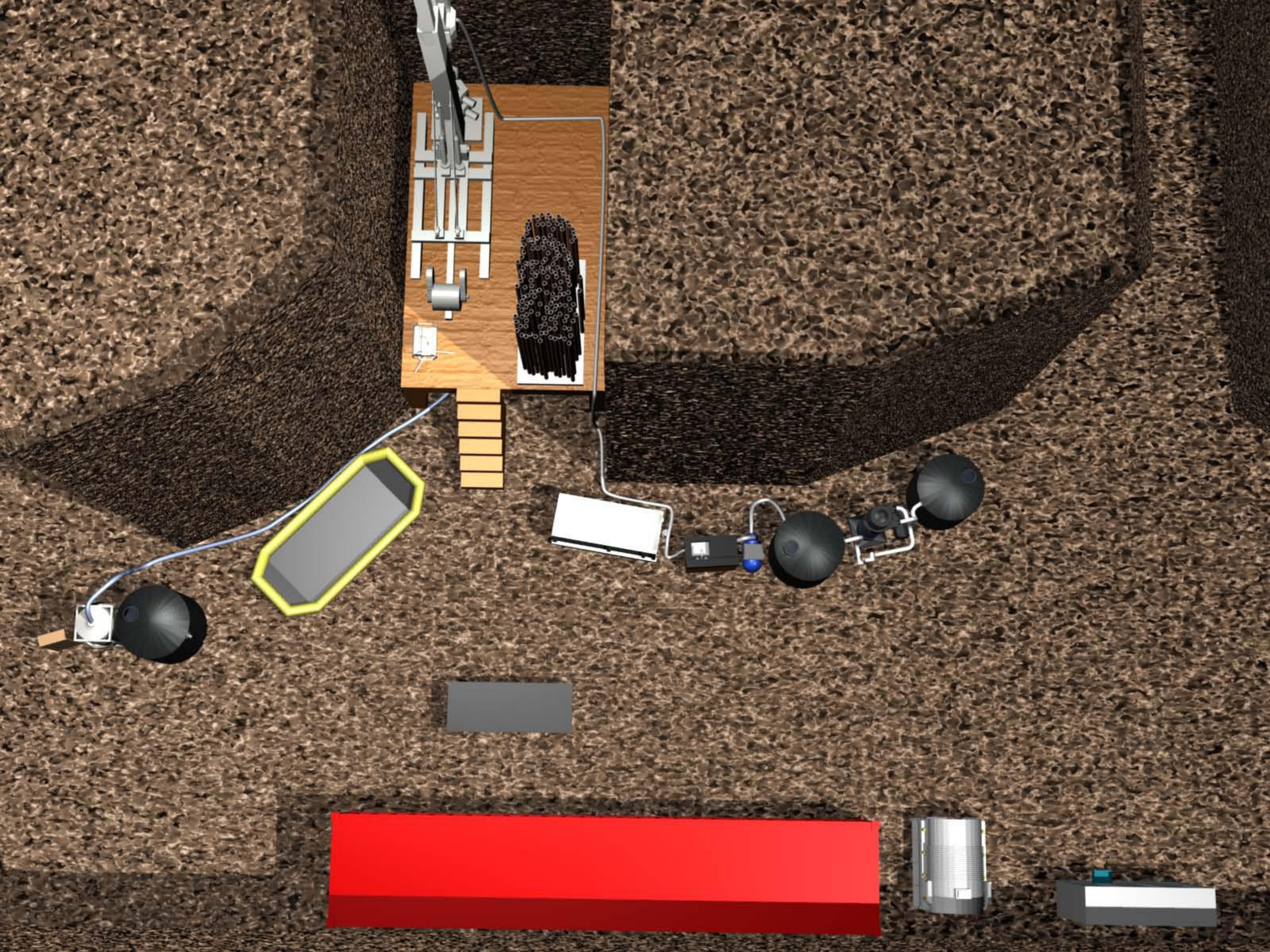
Fracture Flow Facility

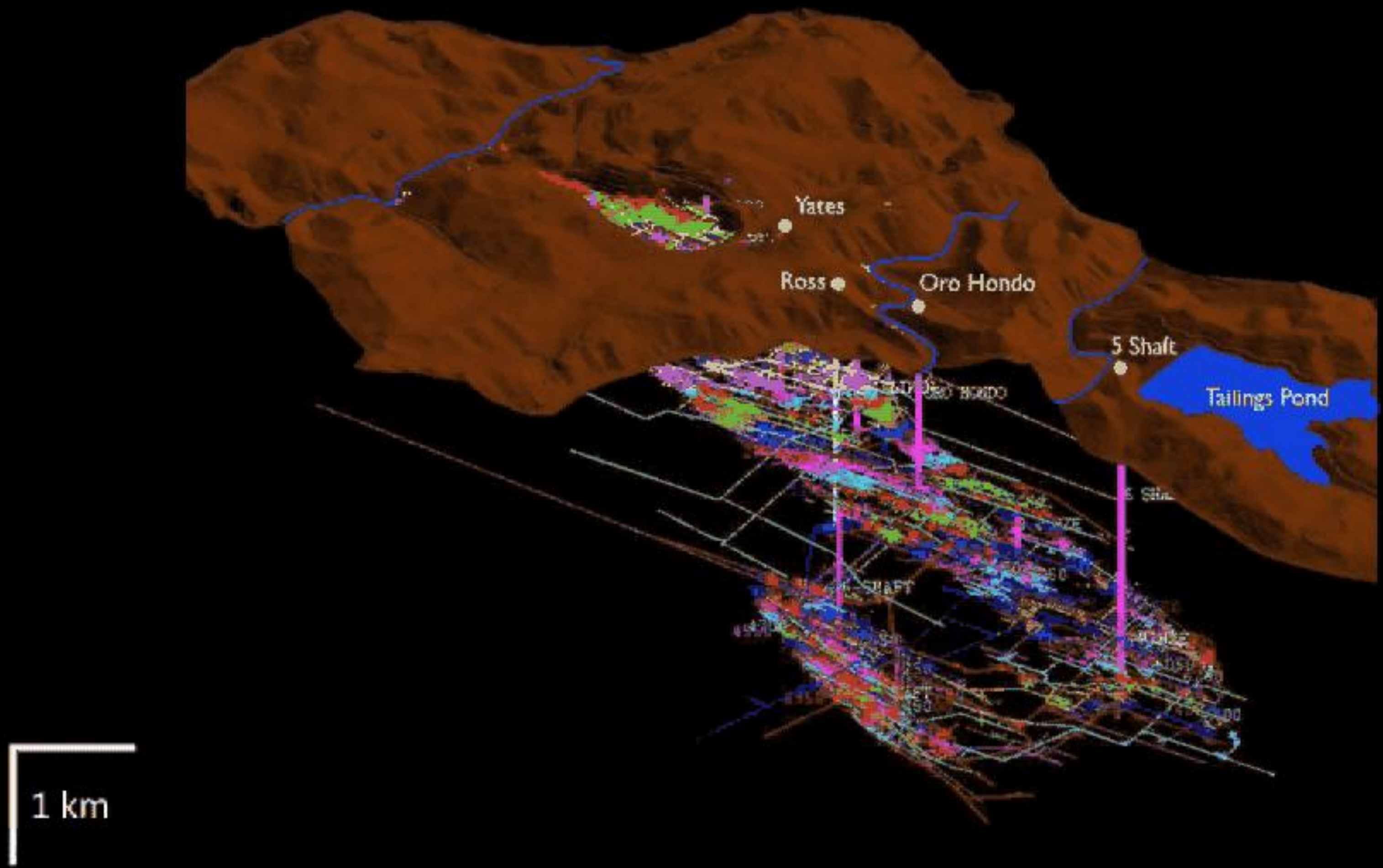
for long term, 3D reactive-transport experiments



Custom built drill that remains on site for borehole installations and maintenance






Yates
Ross
Oro Hondo
5 Shaft
Tailings Pond
1 km

Subsurface Imaging and Sensing

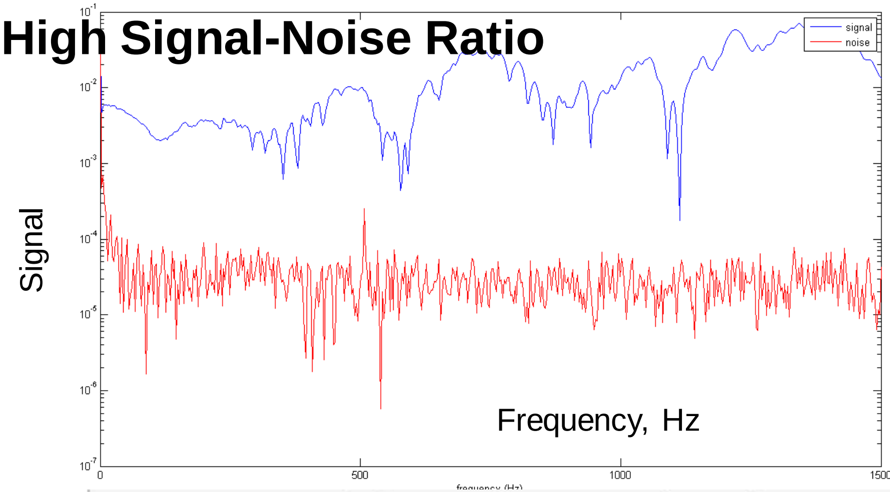
Geoscience Goals

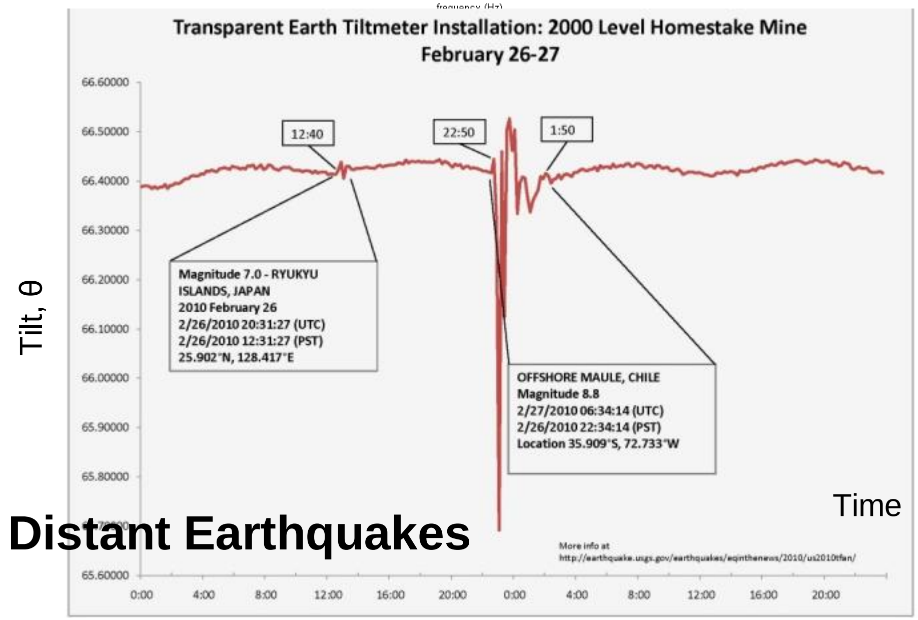
- Constrain source mechanisms
  - Full 3-D coverage
  - Proximal and enveloping measurements
  - Strong coupling
  - Ultra-low-noise environment
- Potential to take seismology from a 10+% to a 1% science

Geoengineering Goals

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

High Signal-Noise Ratio

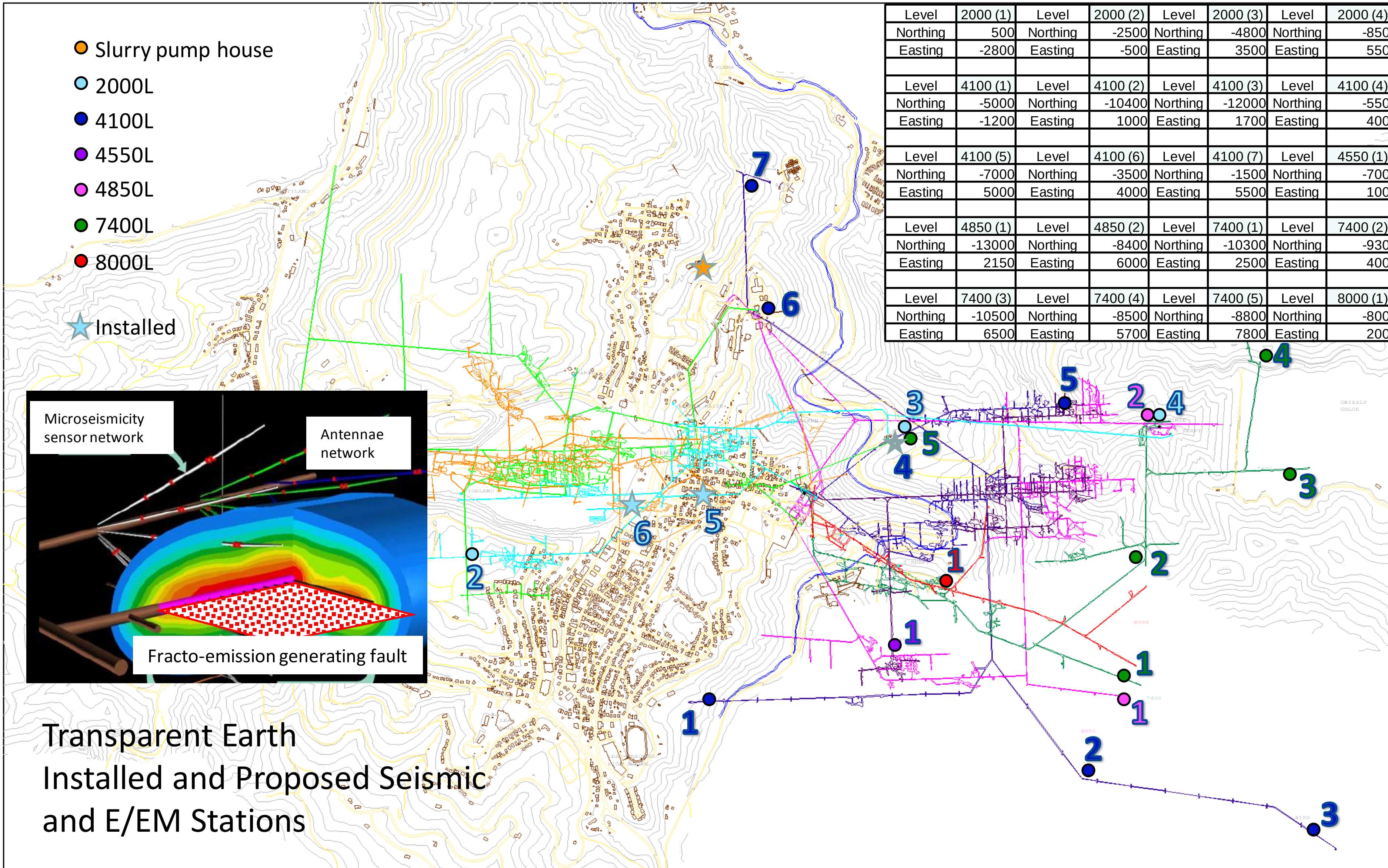




Tilt from Distant Earthquakes

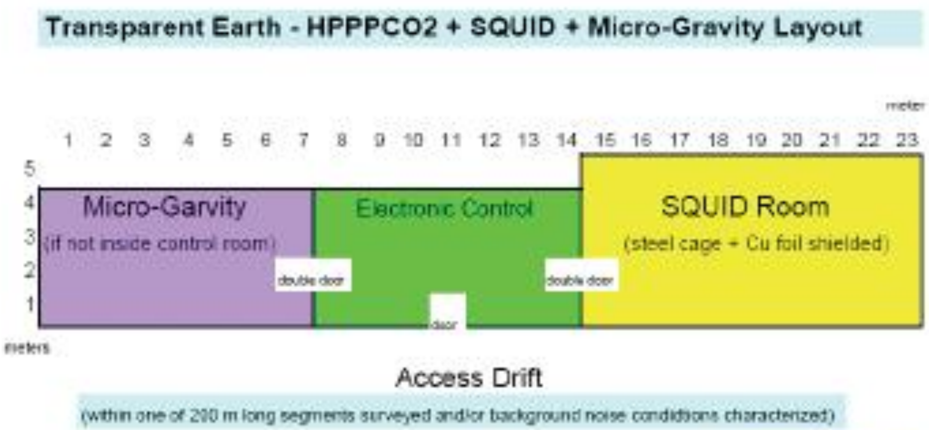
Subsurface Imaging and Sensing – Expt Layout

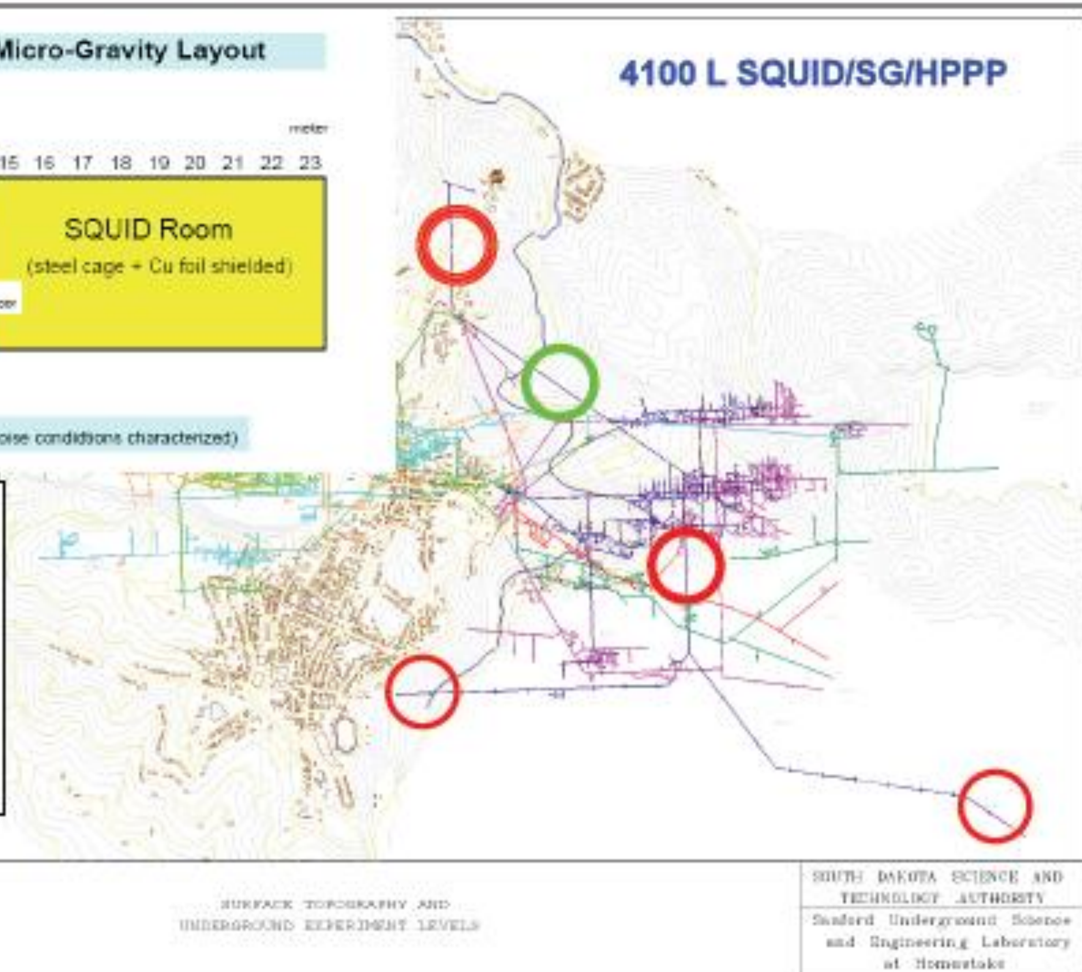
Level	2000 (1)	Level	2000 (2)	Level	2000 (3)	Level	2000 (4)
Northing	500	Northing	-2500	Northing	-4800	Northing	-8500
Easting	-2800	Easting	-500	Easting	3500	Easting	5500
Level	4100 (1)	Level	4100 (2)	Level	4100 (3)	Level	4100 (4)
Northing	-5000	Northing	-10400	Northing	-12000	Northing	-5500
Easting	-1200	Easting	1000	Easting	1700	Easting	4000
Level	4100 (5)	Level	4100 (6)	Level	4100 (7)	Level	4550 (1)
Northing	-7000	Northing	-3500	Northing	-1500	Northing	-7000
Easting	5000	Easting	4000	Easting	5500	Easting	1000
Level	4850 (1)	Level	4850 (2)	Level	7400 (1)	Level	7400 (2)
Northing	-13000	Northing	-8400	Northing	-10300	Northing	-9300
Easting	2150	Easting	6000	Easting	2500	Easting	4000
Level	7400 (3)	Level	7400 (4)	Level	7400 (5)	Level	8000 (1)
Northing	-10500	Northing	-8500	Northing	-8800	Northing	-8000
Easting	6500	Easting	5700	Easting	7800	Easting	2000



Transparent Earth
Installed and Proposed Seismic
and E/EM Stations

HPPP – SQuiD - MicroGravity Experiments





e.g., the MicroGravity monitoring can be used to evaluate changes in ground-water storage changes, quantification of water budgets and aquifer storage properties.

FACILITY-BASED EXPERIMENTS [CO_2/THMCB/FRAX]

Geologic Carbon Storage – Science Drivers

Objectives

•Mechanisms for migration, reaction, and trapping of CO2 in underground aquifers or reservoirs?

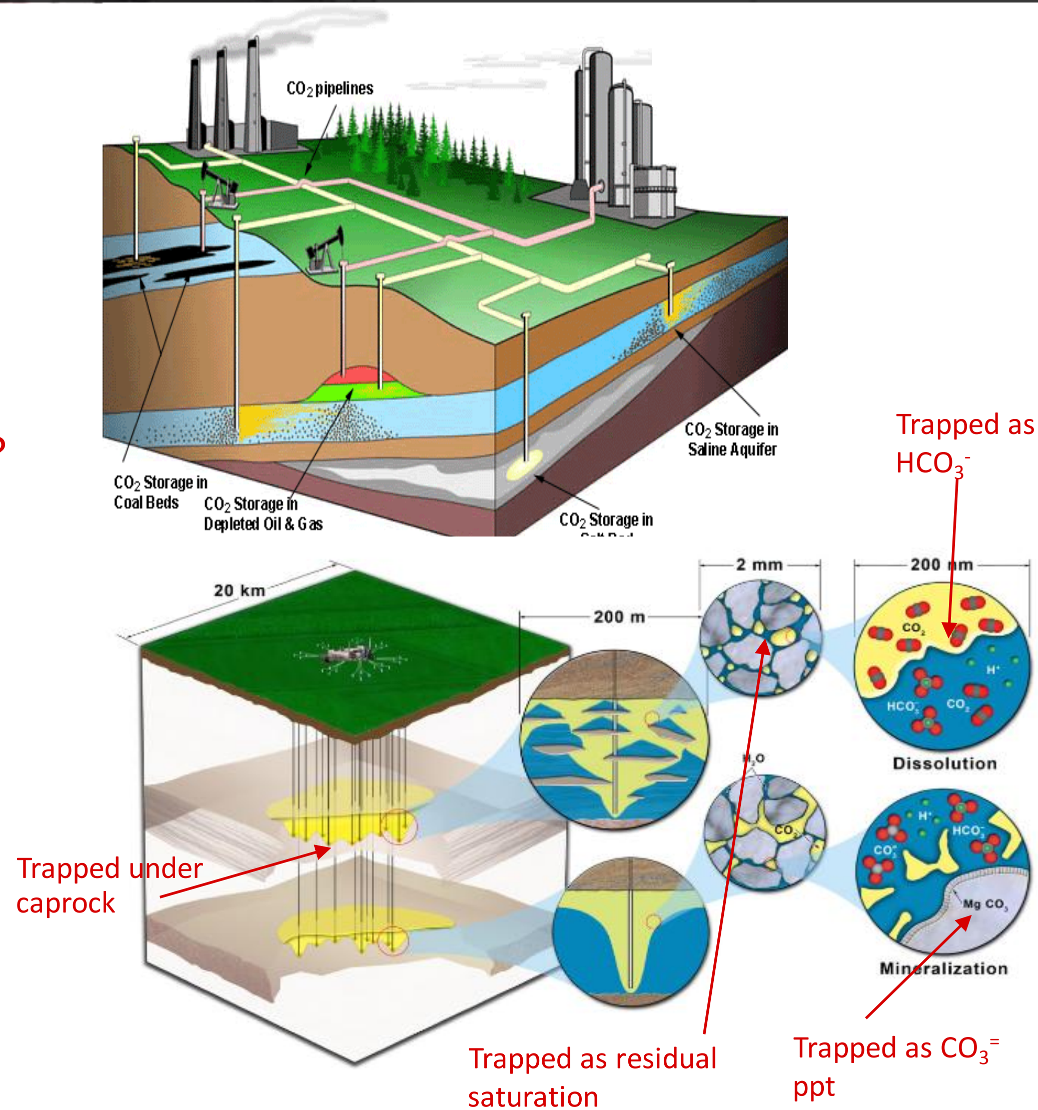
- Will CO_2 flow accelerate due to increasing buoyancy?
- Will Joule Thomson cooling and other processes mitigate buoyancy?

•Interactions of CO_2 with caprocks and well cements.

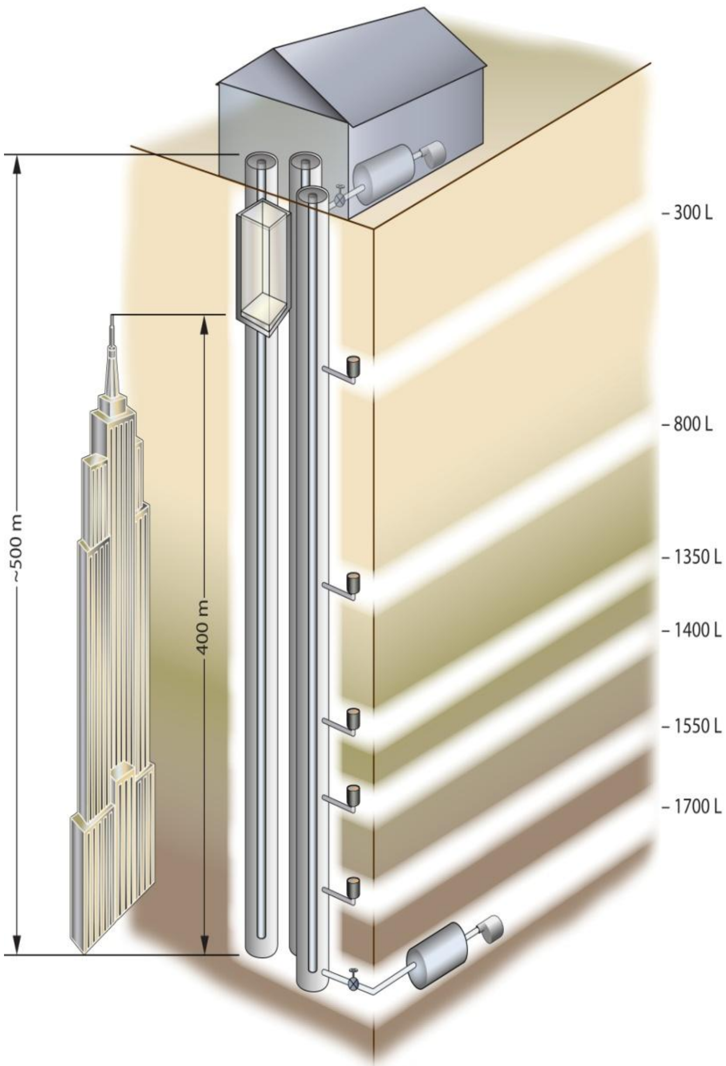
- Will acidic fluids enlarge flow pathways or cause them to self-seal?

•Metabolic potential in caprock shales.

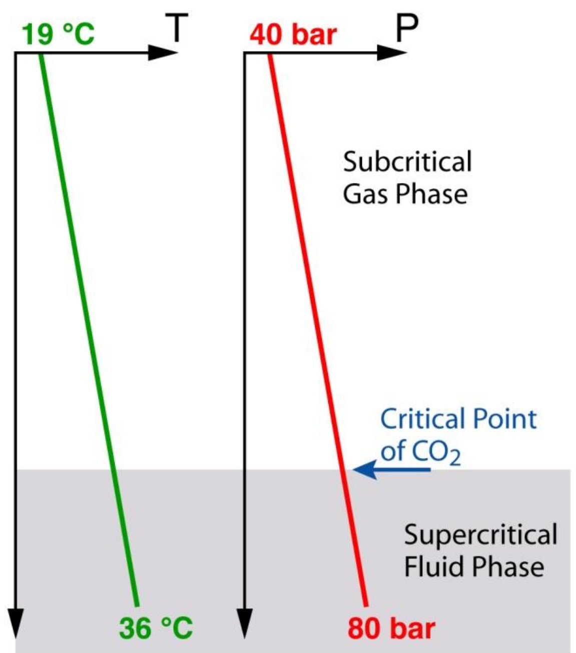
- What are the effects of anaerobic, thermophilic microbial communities on CO_2 conversion to CH_4 and carbonate?



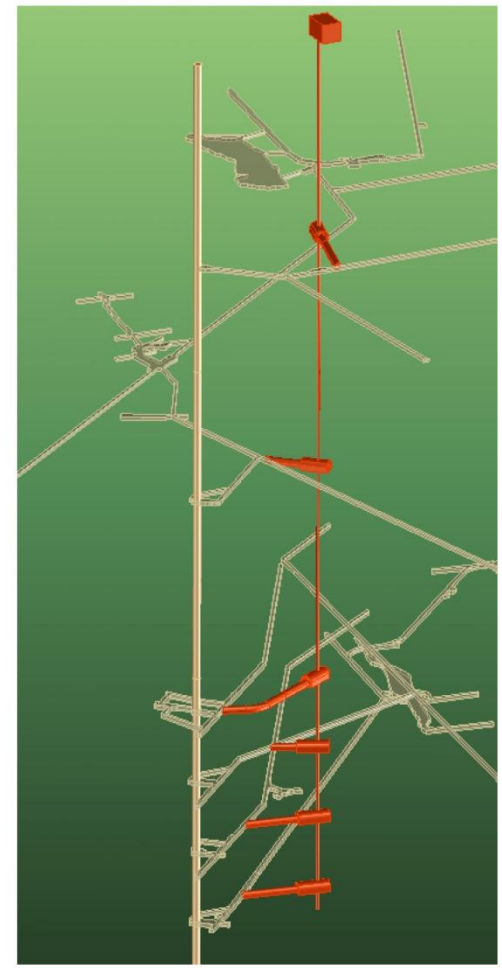
Geologic Carbon Storage – Experimental Layout



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:

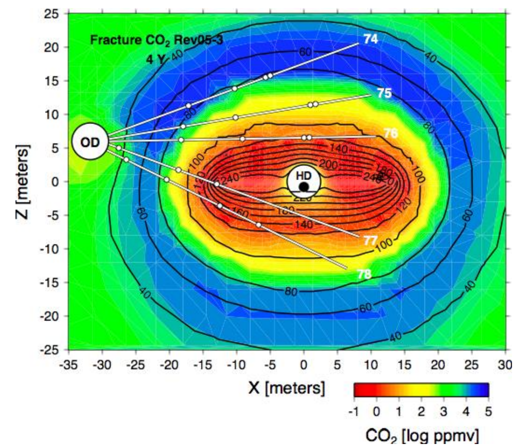
How do mechanical and transport properties evolve and influence fluid chemistry and microbial populations?

Intellectual Merit:

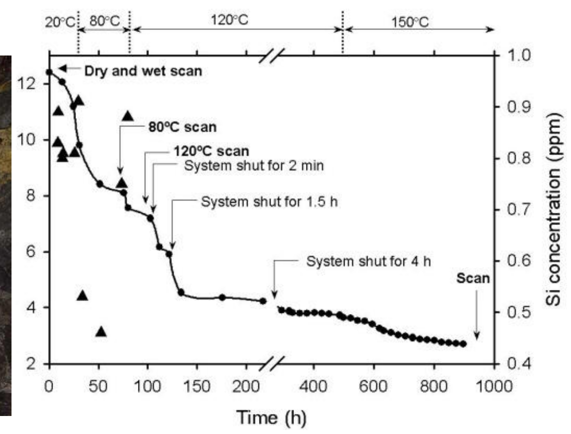
Advance understanding of fault zones, geothermal reservoirs, magmatic-hydrothermal systems, ore mineralization, radioactive waste, other.

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

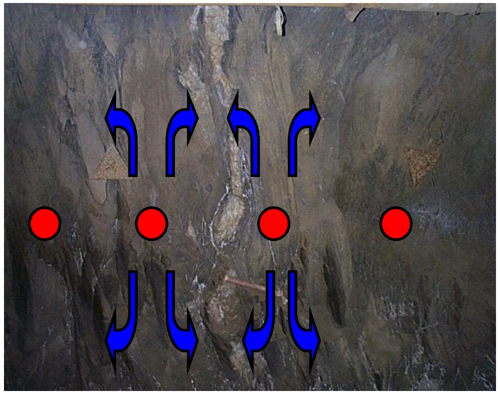
a.) characterize site, b.) install infrastructure
c.) heat d.) monitor e.) core samples
d.) excavate (*mine back*) and describe.

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

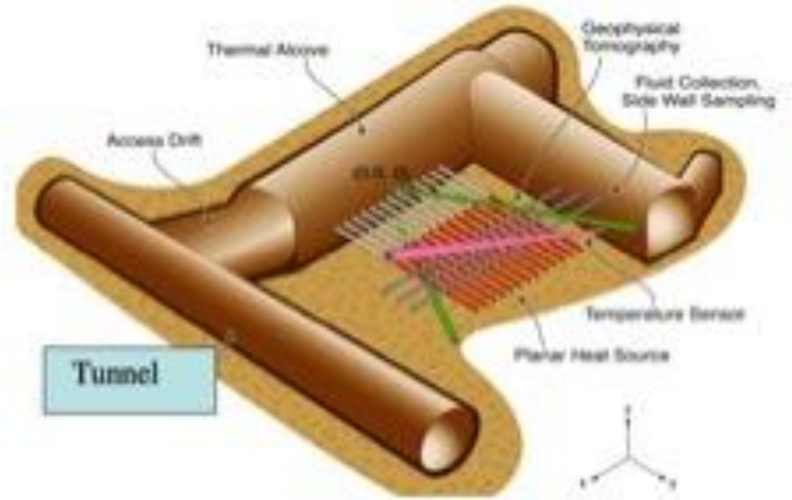
THMCB S4 Tasks

- 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

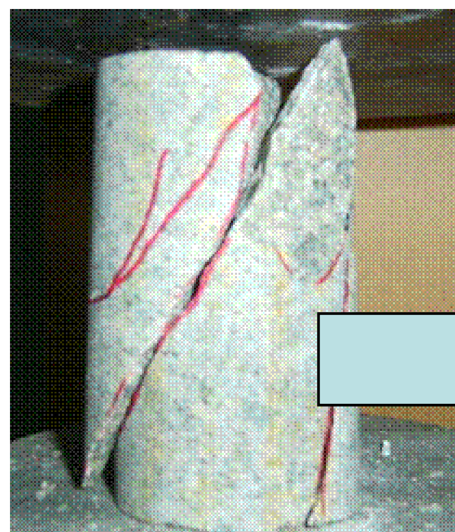


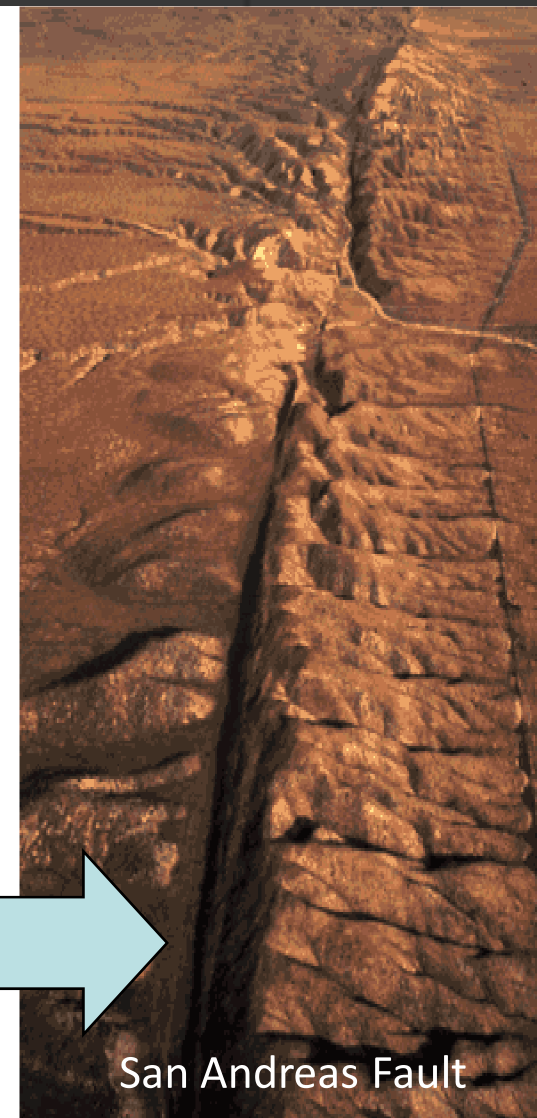
Faulting Processes Experiment – Science Drivers

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….

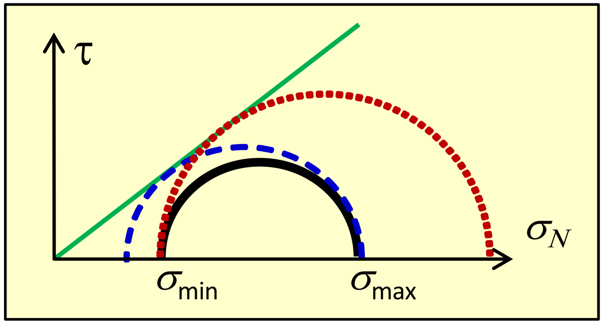


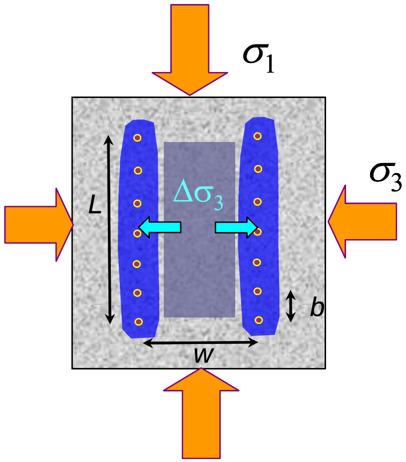


Faulting Processes Experiment – Experimental Layout

Approach

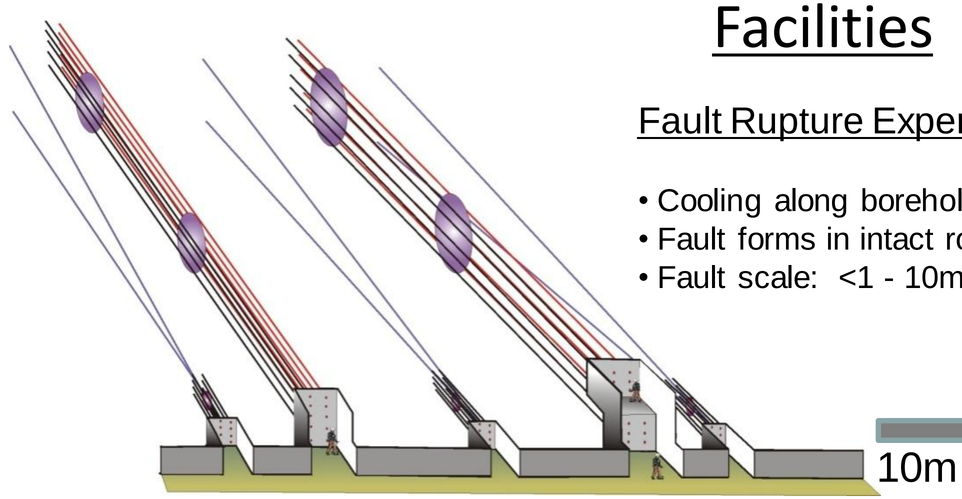
- Faulting by either increasing or decreasing stress





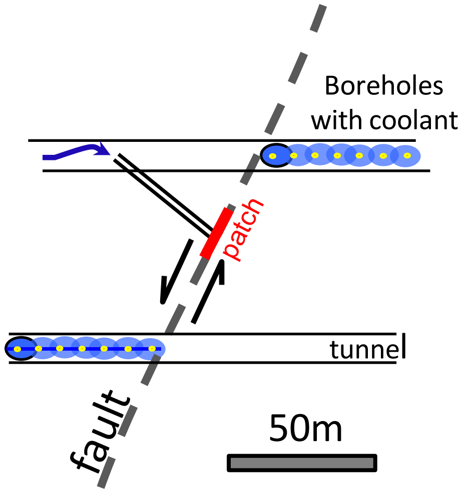
Cooling two rows of boreholes to change stress→ cause faulting

Facilities



Fault Rupture Experiment

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



Slip Propagation Experiment

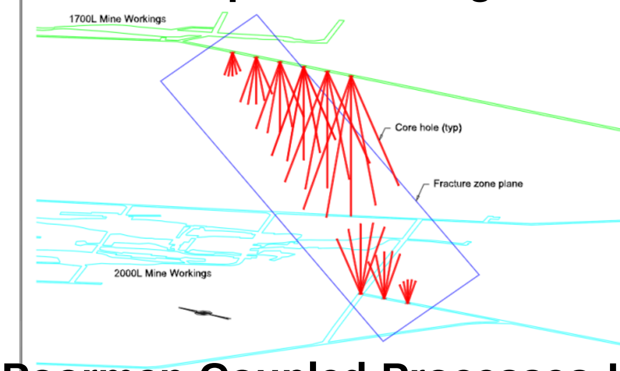
- Cooling on 2 levels to increase shear stress.
- Inject water to initiate slip.
- Slip nucleates on patch
- Patch grows until unstable
- Critical patch size ~ 1m, so need block 10-100m

Active Processes Laboratories at Various Levels

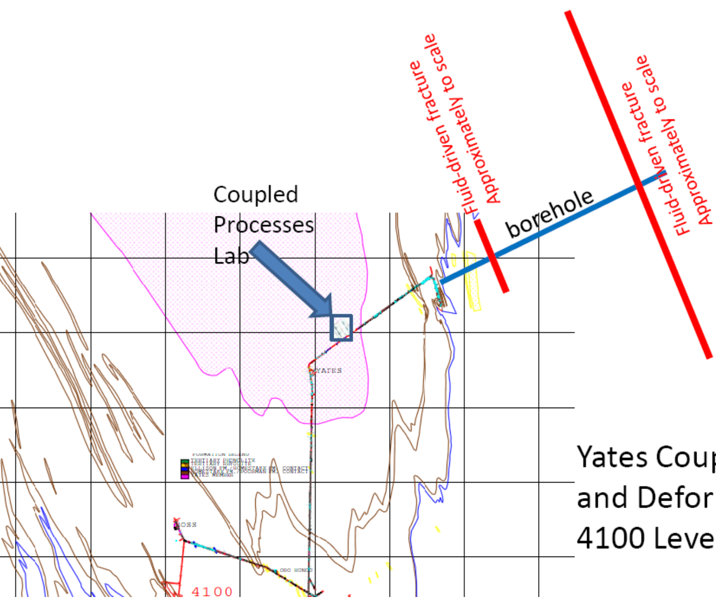
Proposed Levels

1700L+ Fault GeoProcesses Facility
4100L Yates Coupled GeoProcesses Facility
4850L Poorman Coupled GeoProcesses Facility
7400L Deep Coupled GeoProcesses Facility

2000L Slip on Existing Fracture

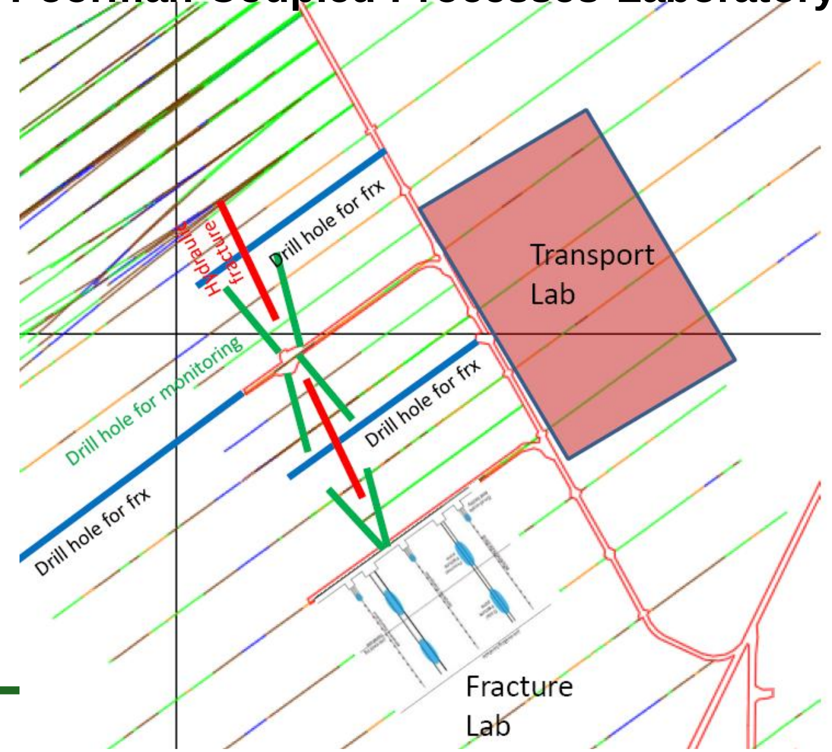


4100L Yates THMCB-Slip Laboratory



Yates Coupled Transport and Deformation Lab 4100 Level

4850L Poorman Coupled Processes Laboratory



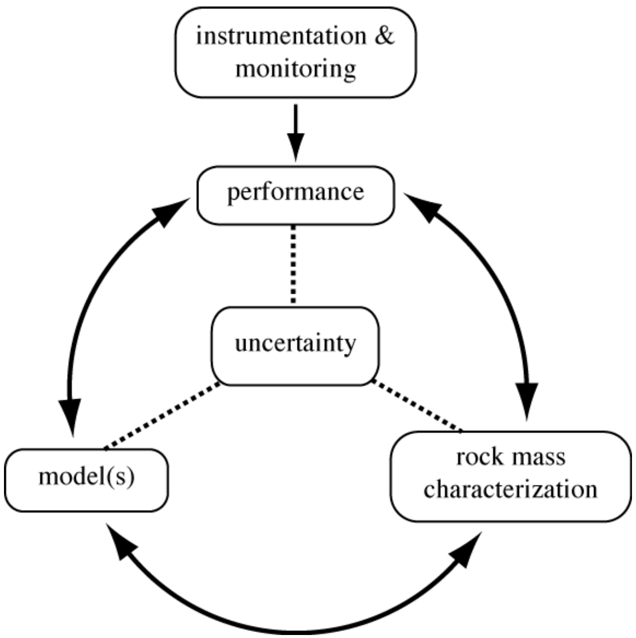
CAVITY EXPERIMENTS

Cavern Design and Instrumentation – Science Drivers

Vision:

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

Concept:



Integrated Suite of Experiments

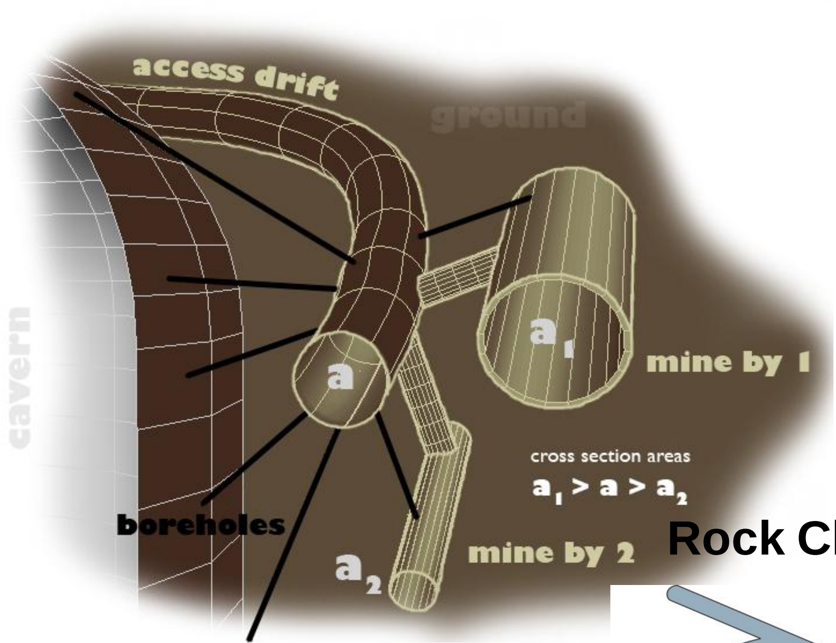
Rock mass characterization
- Fracture Network Characterization
- Digital-Reconstruction of Tunnel Walls
- New Models for Geomechanical Characterization
- Stochastic Characterization of Rock Properties

Scale effects & model(s)
- Geophysical Evaluation of Damage Mechanisms
- Novel Excavation Techniques for Stress Relief
- Scale Effects and Mine-By Experiments
- Mine Pillar Scale Effects
- Engineering of Fractures in Discontinuous Rocks

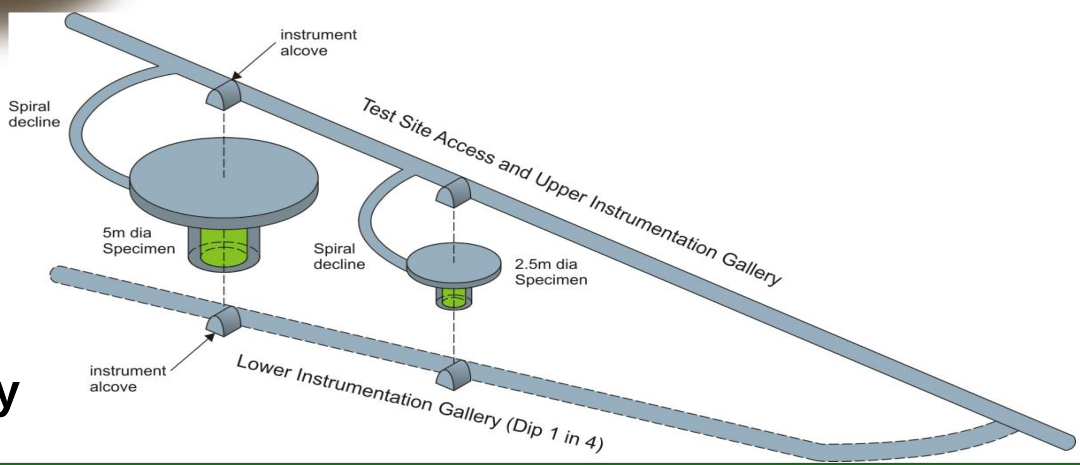
Performance & model(s)
- Optimizing the Locations of DUSEL Caverns
- Cavern Design and Monitoring
- Risk Assessment

Cavern Design and Instrumentation – Experimental Layout

Sensor Array and Mine-By Tunnels

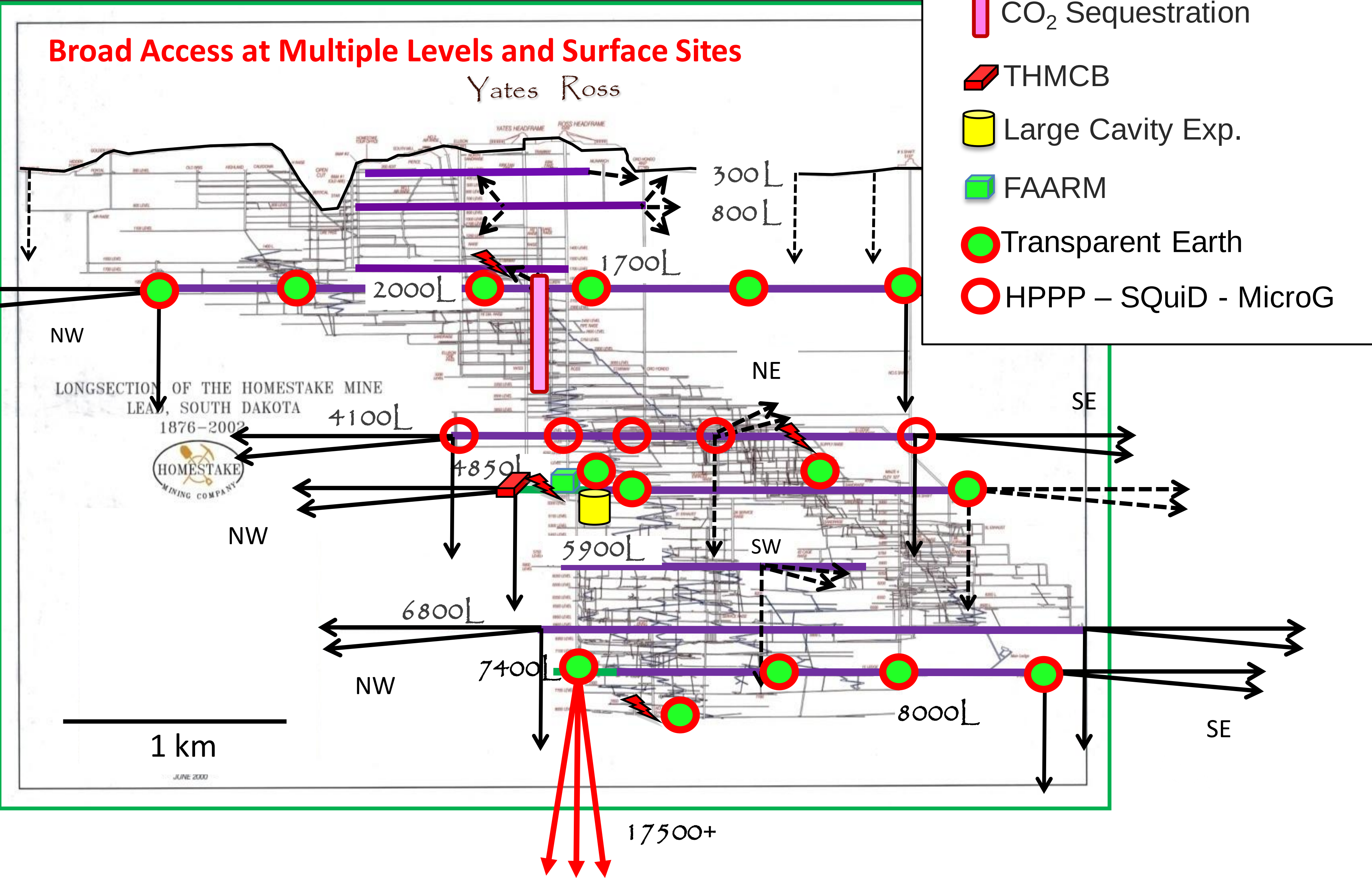


Rock Characterization Experiment



Rock Strength Facility

Experimental Layout



Concluding Remarks- DUSEL Attributes

- DUSEL will represent an important facility with unparalleled attributes:
  - Long-term uninterrupted access to site
    (long term response of structures and active processes)
  - Access to unusual depth for important initiatives in deep science
    (physics and bioscience)
  - Broad access to a large volume of rock
    (scale effects and transparent Earth)

- A facility for world-class science and engineering science in:
  - Physics and Astrophysics
  - Sub-surface Science and Engineering

- Important societal impacts:
  - Construction
  - Energy and sustainability
  - Resource recovery and sustainability
  - Natural Hazards…..