Transparent Earth/Seismic Imaging Team

Steven D. Glaser, working group herdsman

Towards the full Homestake Transparent Earth Observatory – installation and operation of a full complement of seismic, tilt, and EM instrument stations	Steven Glaser, UC Berkeley, Bill Roggenthen, SDSMT, Lane Johnson, LBNL	**EM Passive Imaging as a Hazards Assessment Methodology**	Dante Fratta – University of Wisconsin-Madison
Examining seismic sources from micro to macro through multi-sensor inversion	Steven Glaser, UC Berkeley, Lane Johnson, LBNL, Bill Roggenthen, SDSMT	**Active source experiment to study anisotropy**	Gary Pavlis, Indiana University
Installation of the Rapid City long-period station at the Homestake	Lind S. Gee, scientist-in-charge USGS Albuquerque	3D, Time-Lapse Seismic Tomography for Imaging Overburden Changes due to Dewatering	Erik Westman, Virginia Tech
Stress Monitoring with high precision seismic travel time measurements	Fenglin Niu, Rice U; Tom Daley, LBNL	**Understanding the complexity of the crustal Earth system**	Christian Klose, Columbia University
Advanced Imaging of Gravity Variations and Rock Structures	Don Pool, USGS, Phoenix; Joe Wang, LBNL	**3-D passive electromagnetics for structural imaging, anisotropy, and methodological studies**	Paul Bedrosian, Vic Labson, US Geological Survey, Denver
Prototype Broadband Array for DUSEL	Gary Pavlis, Indiana University	**3D resistivity & self-potential monitoring of mine dewatering phase**	Burke Minsley; Vic Labson, US Geological Survey, Denver

Infrastructure needs prior to conducting any experiments at Homestake

All experiments in the mine will require some minimum of service and facility.
We assume that all experiments will need at least the following infrastructure.

- High-speed fiber internet links that provide IEEE1588 time synchronization.
- Power over ethernet?
- A clean, dry, ventilated, and very well lit enclosed space approximately the size of a half-container (6 x 2.5 x 2.5 m). Referred to here as a "doghouse."
- **Clean**, conditioned power, 30 to 50 amps at 110/120 VAC.
- Access to drinking water and sanitary facilities.
- Each team needs a full-time, high level tech at the DUSEL.

Infrastructure needs prior to conducting any experiments at Homestake

- Ongoing work to provide reasonable estimates of bulk Vp and Vs.
- Detailed velocity models to characterize the effects of the mined out volumes.
- Areas of low EM
- Access to far reaches of the mine.

- Effects of ferrous materials dependent upon the EM application.
- Find isolated locations for measurements extremely sensitive to possible near field effects.

- The ramp systems, which connect the levels with ~50m vertical separation will provide areas without metal.
- Fiberglass rock bolts could be used in these areas to reduce the effects of steel ground control equipment even further.

Seismic Imaging of Subsurface Stress

Fenglin Niu Rice University
P. G. Silver, *Carnegie Institution of Washington*
T. Daley, *Lawrence Berkeley National Lab*

The time-varying stress field at depth is perhaps the most crucial parameter for understanding the earthquake triggering process.

The Speed of Seismic Waves is a Measures of Stress in Rocks. This holds at seismogenic depth and can be used as a "stress meter".

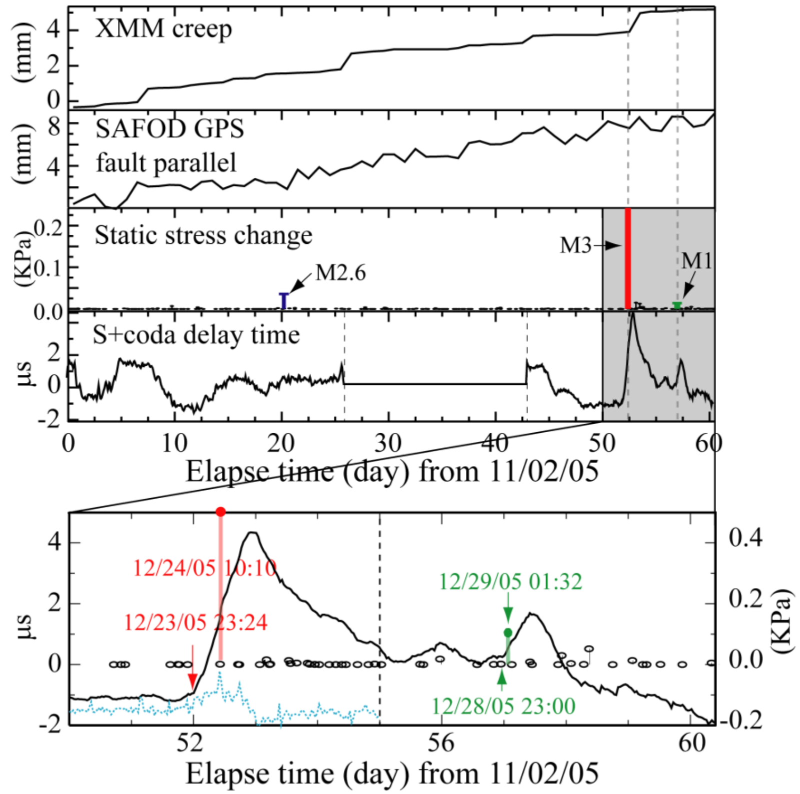
Why at Homestake?

Stress changes at seismogenic depth could be more difficult to observe with conventional surface instruments.

Temperature variation at surface is a large noise source in the electronics.

Deep observation could avoid surface environmental effects, such as precipitation.

Need a deep natural experiment site that bridges laboratory study and large scale seismic experiment.



Stress Monitoring with high precision seismic travel time measurements. **Fenglin Niu**, Rice U; Paul Silver Carnegie Institute, Tom Daley, LBNL.

- High-precision multi-path travel time measurement to determine relation between stress and velocity, stress and seismic anisotropy
- Use coda wave interferometery to image change in the scattering field that links to fluid migrations
- 3 wells, ~10-50 m long or deep, variable spacing
- Wells ideally near fracture zone or spanning the zone.
- Temperature controlled facility (21 ~ 22℃, rH 65 ~ 70%)
- Max occupancy four persons, with an average of one

3D, Time-Lapse Seismic Tomography for Imaging Overburden Changes due to Dewatering. **Erik Westman**, Virginia Tech

- This project will use data collected by the permanent seismic observatory. No infrastructure needed

Understanding the complexity of the crustal Earth system. **Christian Klose**, Columbia University.

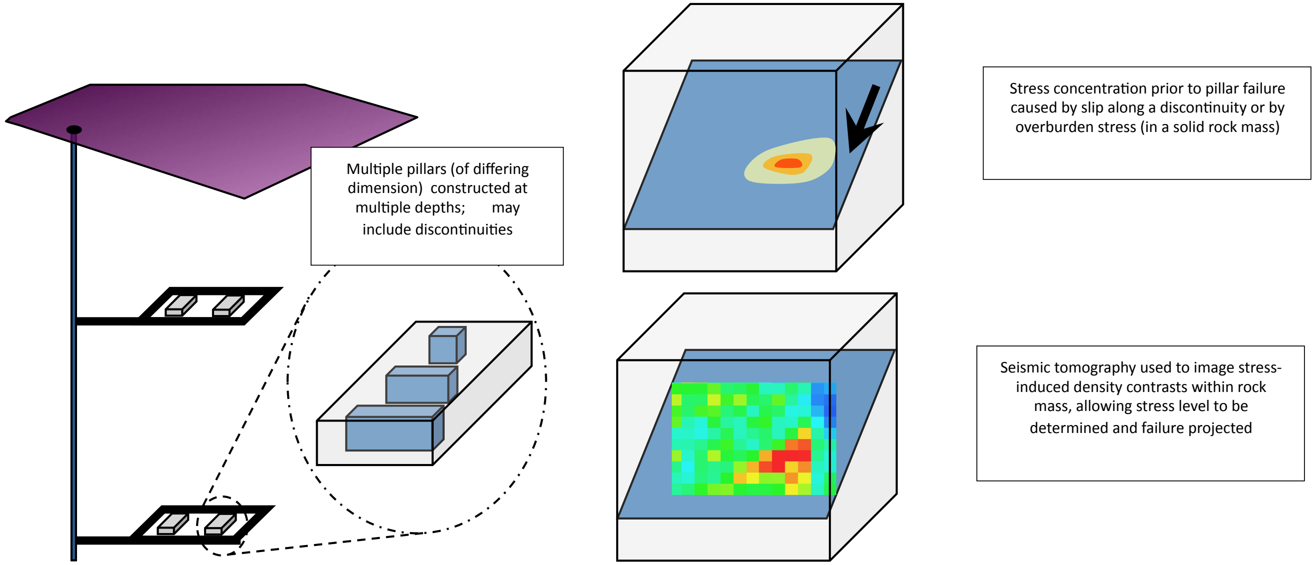
- This experiment will make use of almost all streams of data from the observatory, and extensive calculations and imaging will be performed off-site.

TOMOGRAPHIC IMAGING OF STRESS-REDISTRIBUTION FOR PREDICTION OF CATASTROPHIC ROCK MASS FAILURE

Erik C. Westman , Virginia Tech

Catastrophic failure extends to all aspects of rock mechanics including tunnels, mines, rock slopes, earthquakes, waste repositories, and bridge and dam abutments

Accomplishing the ultimate goal of predicting these catastrophic failures will result in significantly reduced fatalities, lowered construction costs, and increased environmental protection.



Rock failures are associated with the redistribution and concentration of stresses from mine excavations

To predict rock failure, monitor the redistribution of stresses within the rock.

Use tomograms of seismic stress field to image redistribution of stress

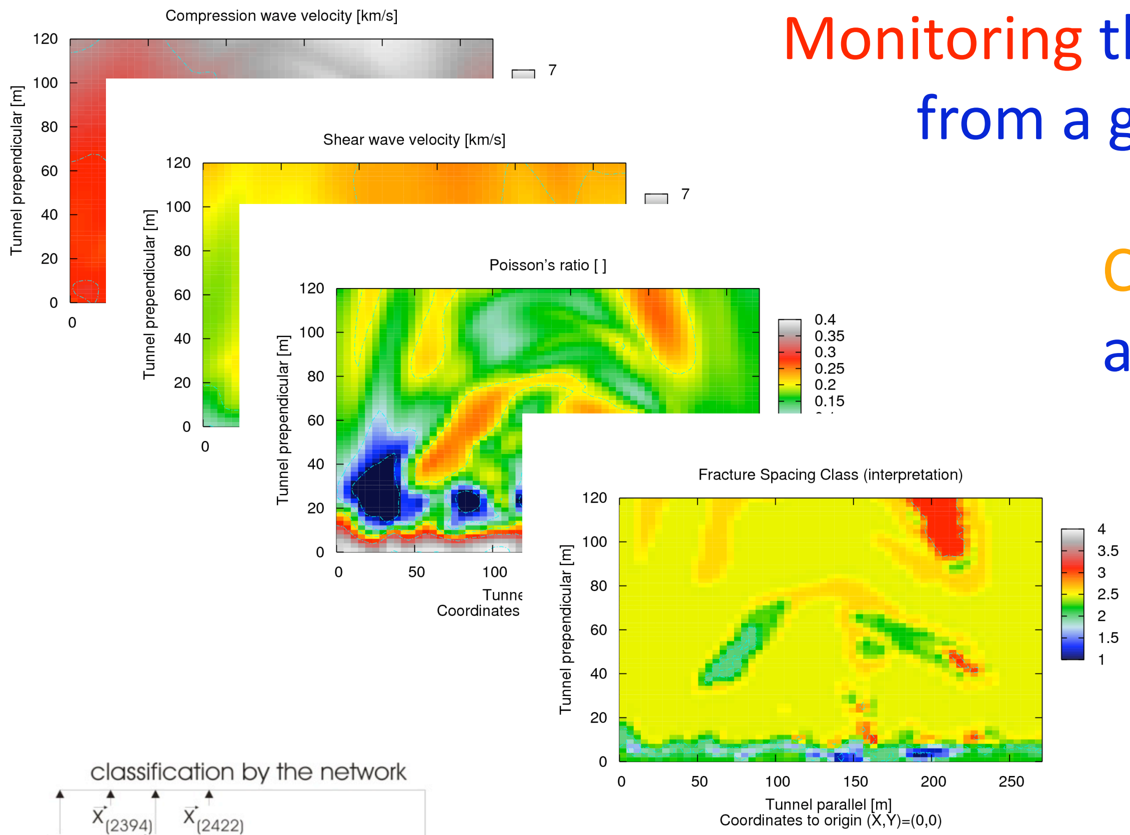
Shown clearly in the laboratory but limited testing at the field scale.

This experiment will enhance miner's life safety

This experiment will put the method of imaging stress-induced changes within rock masses on a sound theoretical and practical basis. It requires a DUSEL, as deep, long-term, dedicated access is not available at current underground tests sites.

New Methods of Geoscientific Data Interpretation based on Machine Intelligence

by C.D. Klose



Monitoring the Earth's system from a global perspective.

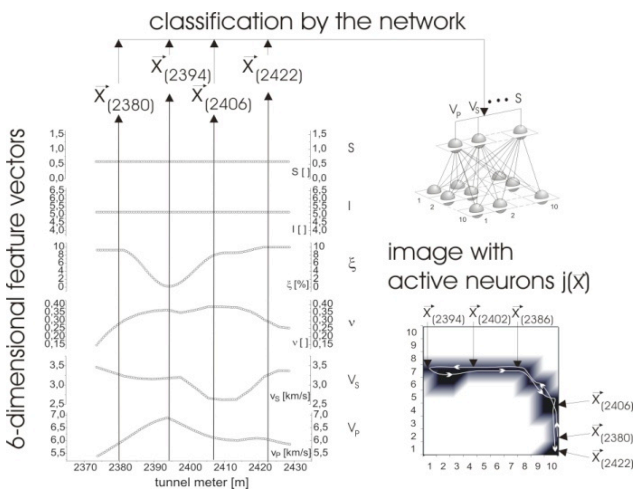
Geophysics

Classify multi-dimensional and complex data

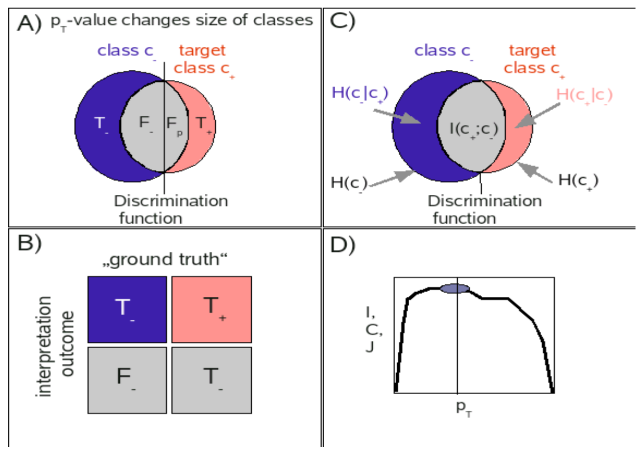
Engineering, Biology, Geology

Interpret & Predict in areas of interest

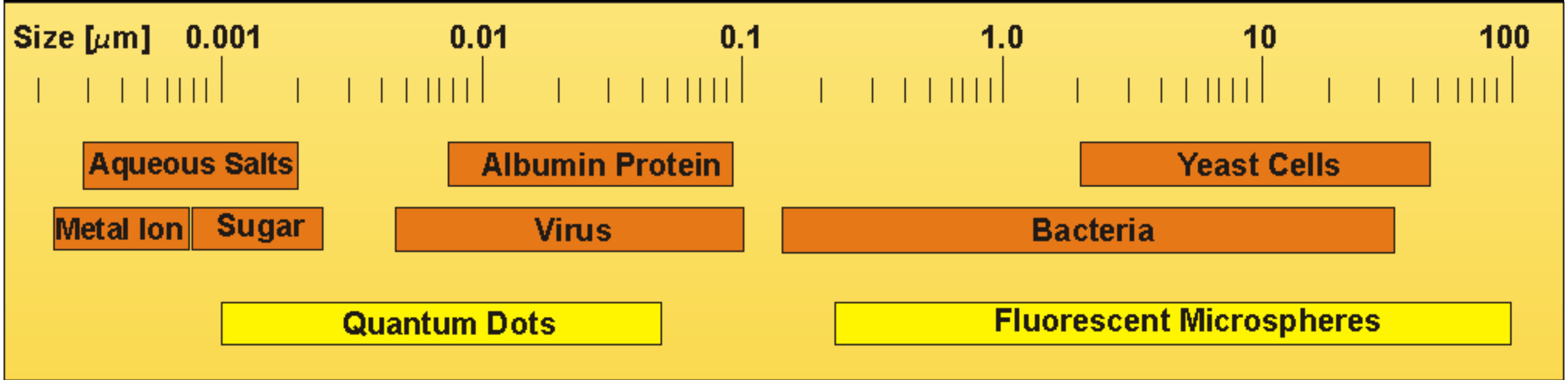
- zones of weakness
- seismic events
- zones of fluid migrations

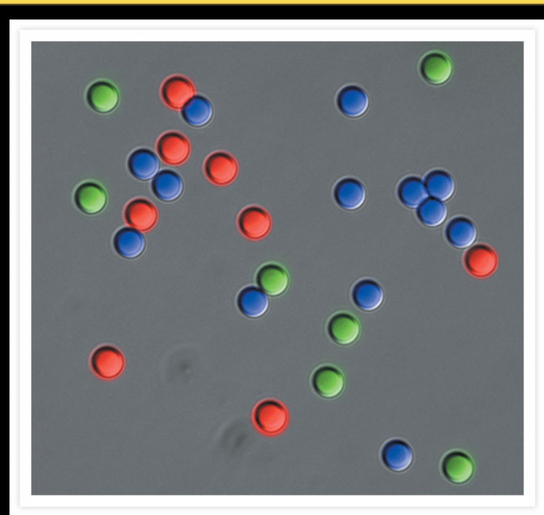


Machine Intelligence methods perform data interpretation and uncertainty estimation



Determining Fluid Transport Mechanisms with Fluorescence





The size of a quantum dot determines it's fluorescent properties. Fluorescent microspheres can be purchased in many sizes with many different dyes. Fluid transport can be determined over 5 orders of magnitude in size. All that is needed is access to boreholes/fissures in rocks to introduce dots and microspheres and sample water.

Quantum dots and fluorescent microspheres for determining fluid transport mechanisms. **Nathan Bramall**, NASA-Ames.

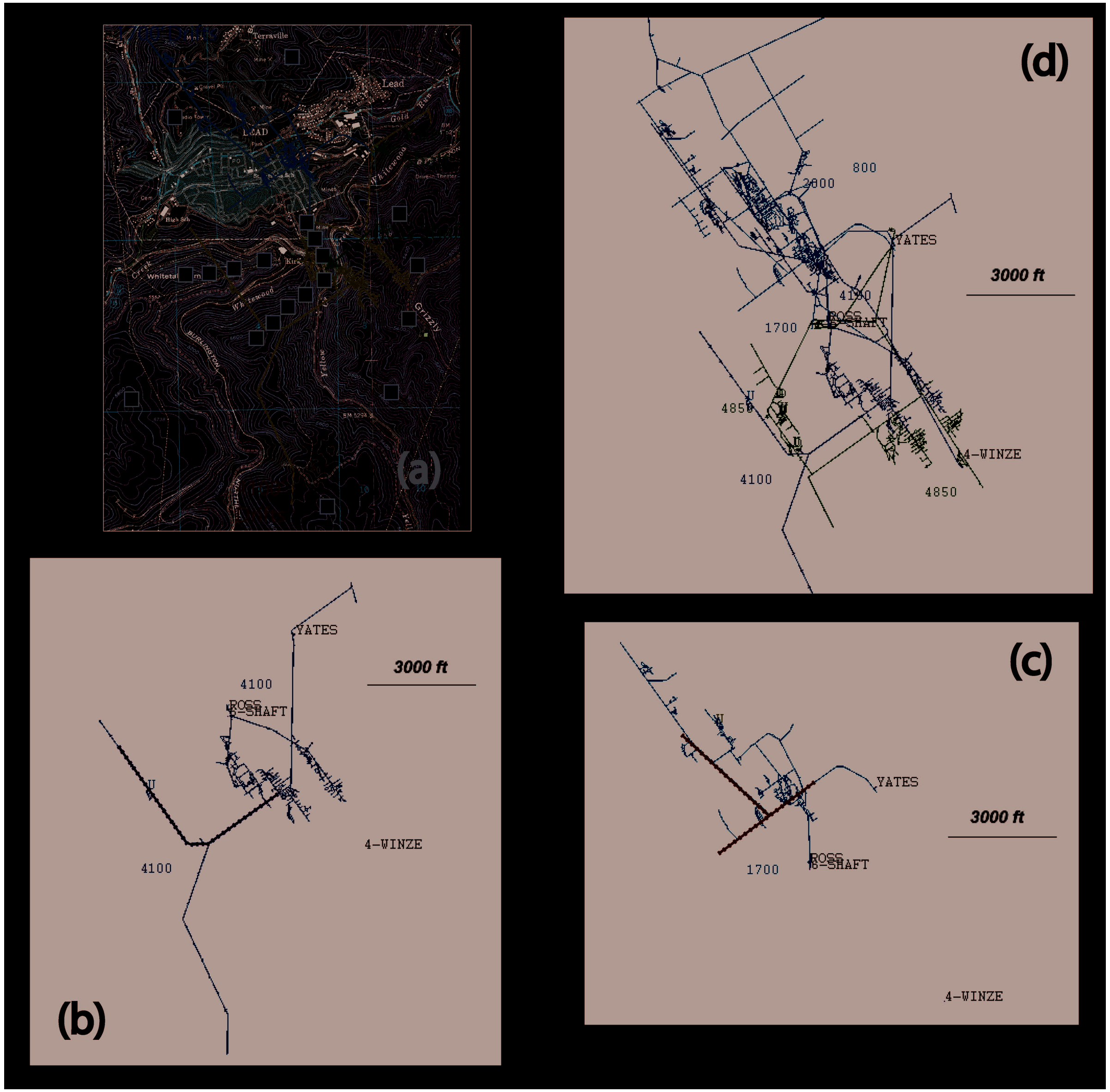
- 1 doghouse for sterilized lab, 5 ~ 25℃
- Approximately 200 l of sterilized water needed at fixed site
- Chemicals - fluorescent markers
- 100 holes to introduce markers, 300 ~ 400 for monitoring.
- Use existing 75 mm holes, additional holes < 1 m deep
- Tracers are non-recoverable, fluorescent materials are inert
- 6500, 6950, 7400, and 8000 levels
- two-week periods once or twice a year for three years

(a) surface array - Yellow squares are approximate station locations

(b) location for a cross array with 40 elements spaced at 50 m for 4100' mine level, array location is shown as the yellow lines hatched at 50 m intervals

(c) planned locations for the 1700' level, array location is shown as blue and the entire set of drifts at this level are red.

(d) Color codes for (b) and (c) are combined to illustrate horizontal relations of 1700 and 4100 foot array elements



Prototype Broadband Array for DUSEL S-4. **Gary Pavlis**, Indiana U.

Active source experiment to study anisotropy. **Gary Pavlis**, Indiana U.

- Use instruments borrowed from IRIS
- 0.5 m^2 concrete pads on founded-in-rock piers
- 10-pound sledge hammer source

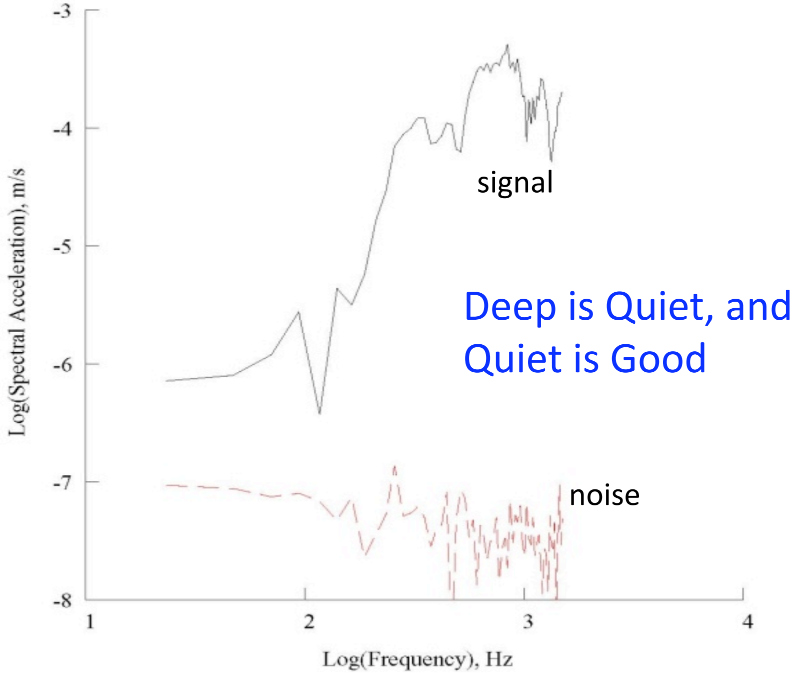
Prototype Broadband Array for DUSEL S-4. **Gary Pavlis**, Indiana U.

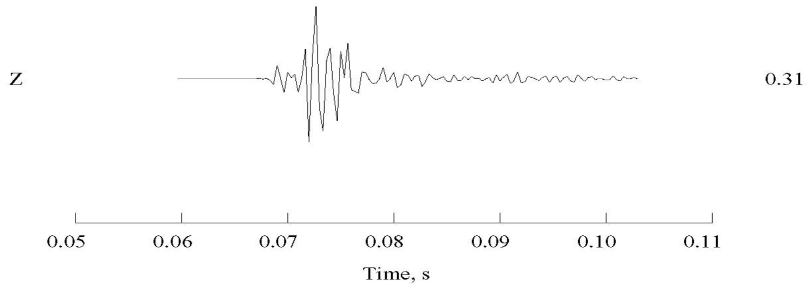
- 25 to 35 broadband instruments throughout mine, record continuously for approximately two years
- Part permanent, part will be temporary , fixed or roaming
- 0.5 m^2 concrete pads on founded-in-rock piers
- Installation - 2 or 3 people, 2 ~ 3 weeks, visit every 6 to 9 months
- The deeper the better
- 1 m^3 cases (25 to 35), store off-site

Towards a Transparent Earth

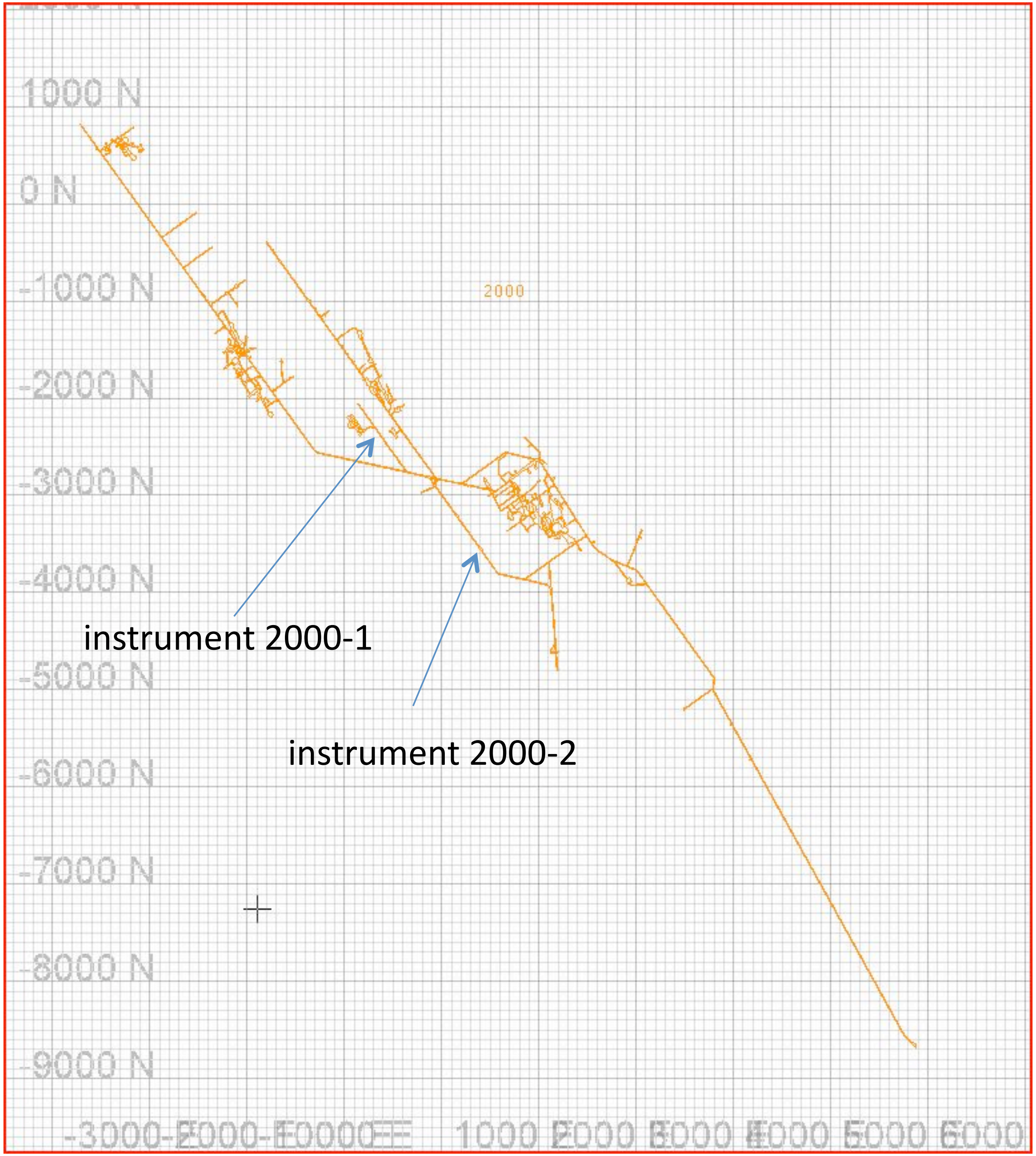
S.D. Glaser, *UC, Berkeley*
W. Roggenthen, *SDSMT*
L.R. Johnson, E.L. Majer, *LBNL*

Install an acoustic “microscope” surrounding the Homestake workings –
1st NSF funded DUSEL research



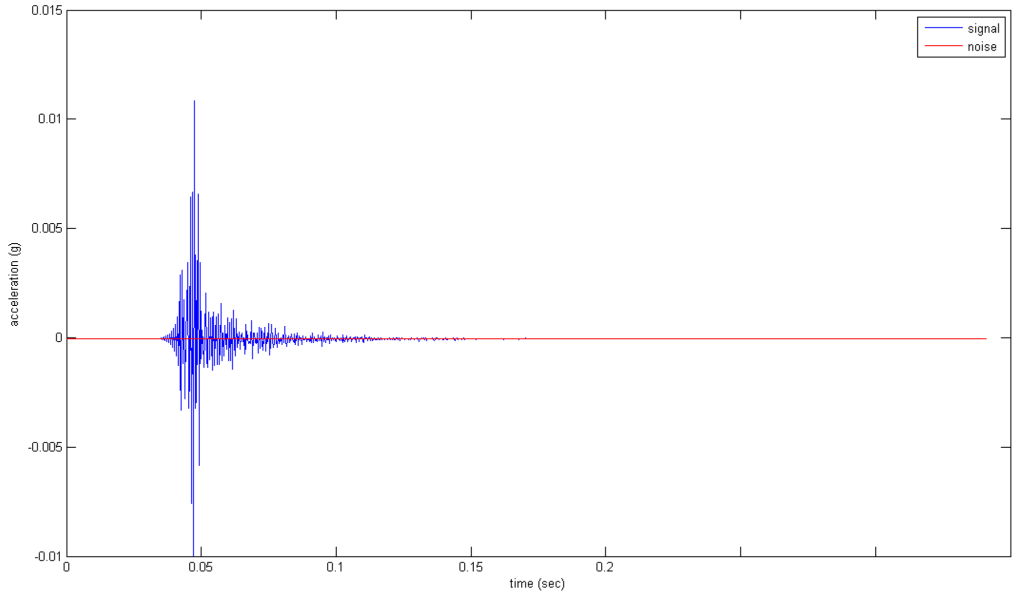


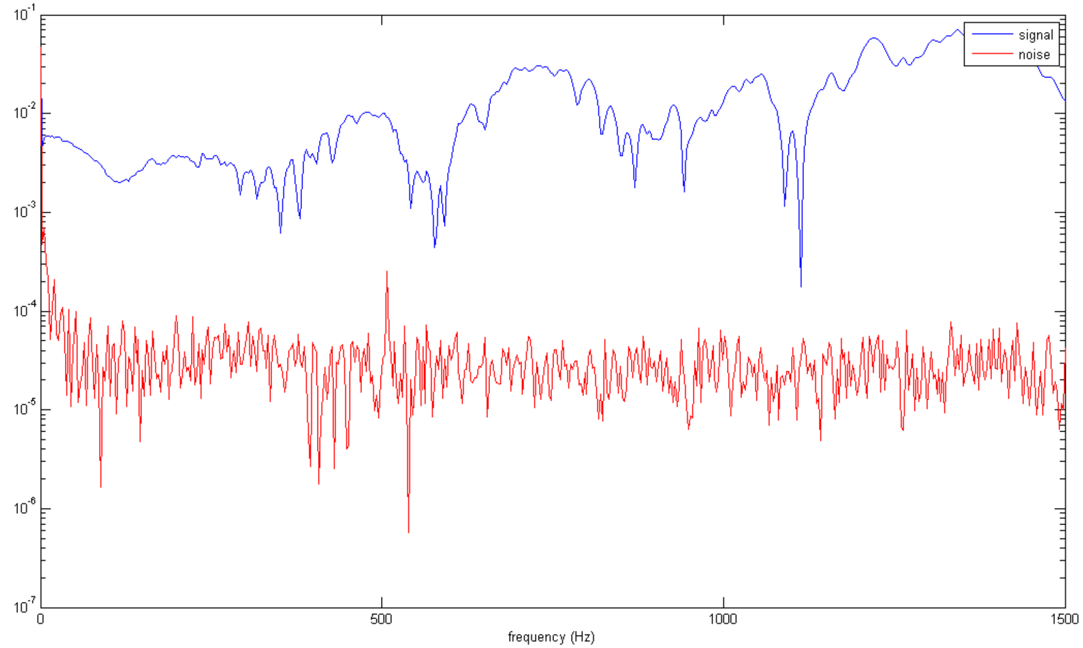
1) Develop deep in-situ seismic observatory for rapid imaging of dynamical geo-processes at depth.
2) Provide rock mass dynamics and safety information to miners and tunnelers
3) Provide an infrastructure for all earth scientists
4) Improve ability to detect and characterize underground structures and activity



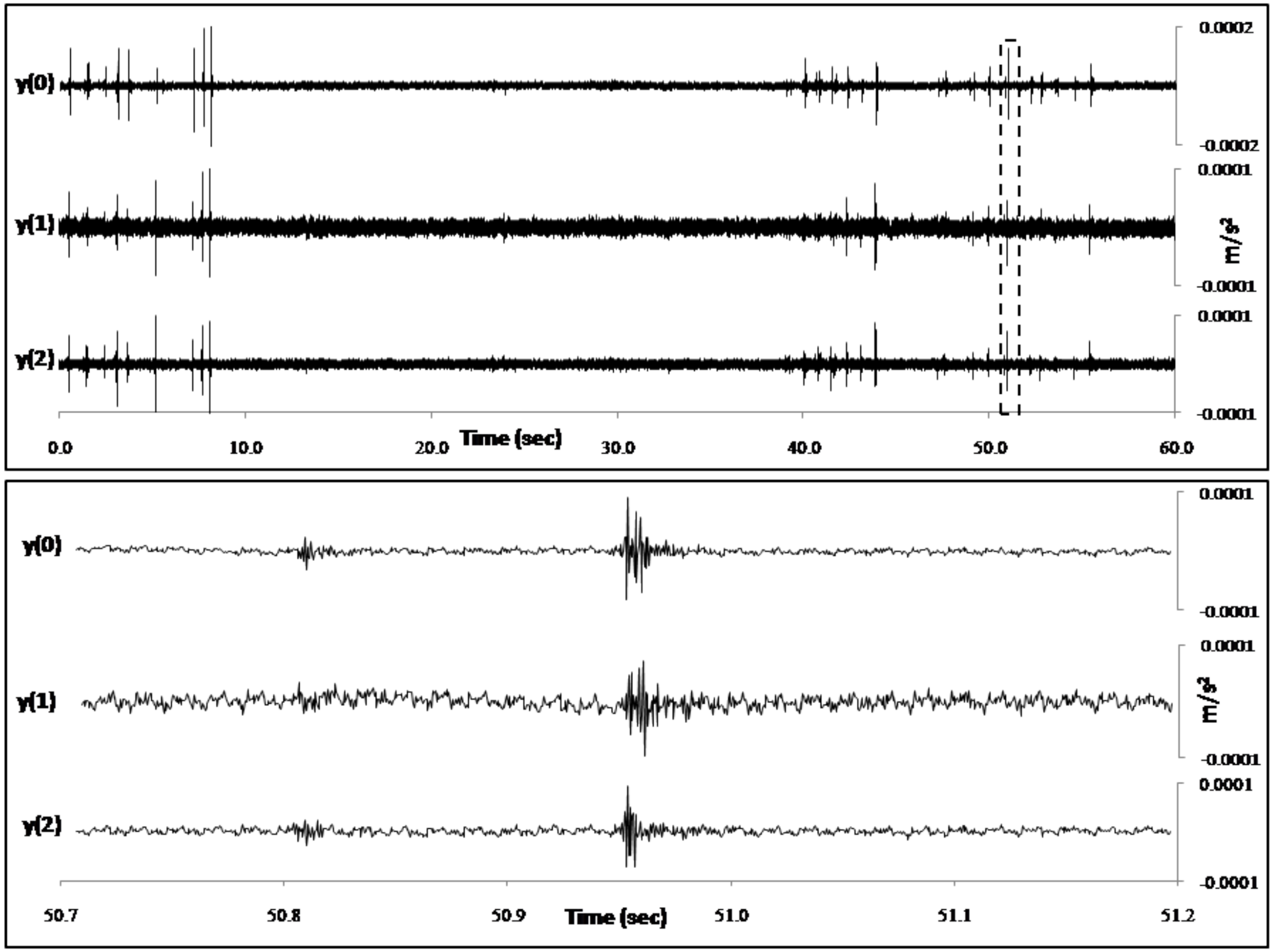
1000 N
0 N
-1000 N
-2000 N
-3000 N
-4000 N
-5000 N
-6000 N
-7000 N
-8000 N
-9000 N
2000
instrument 2000-1
instrument 2000-2
1000

Transparent Earth 2000L Station

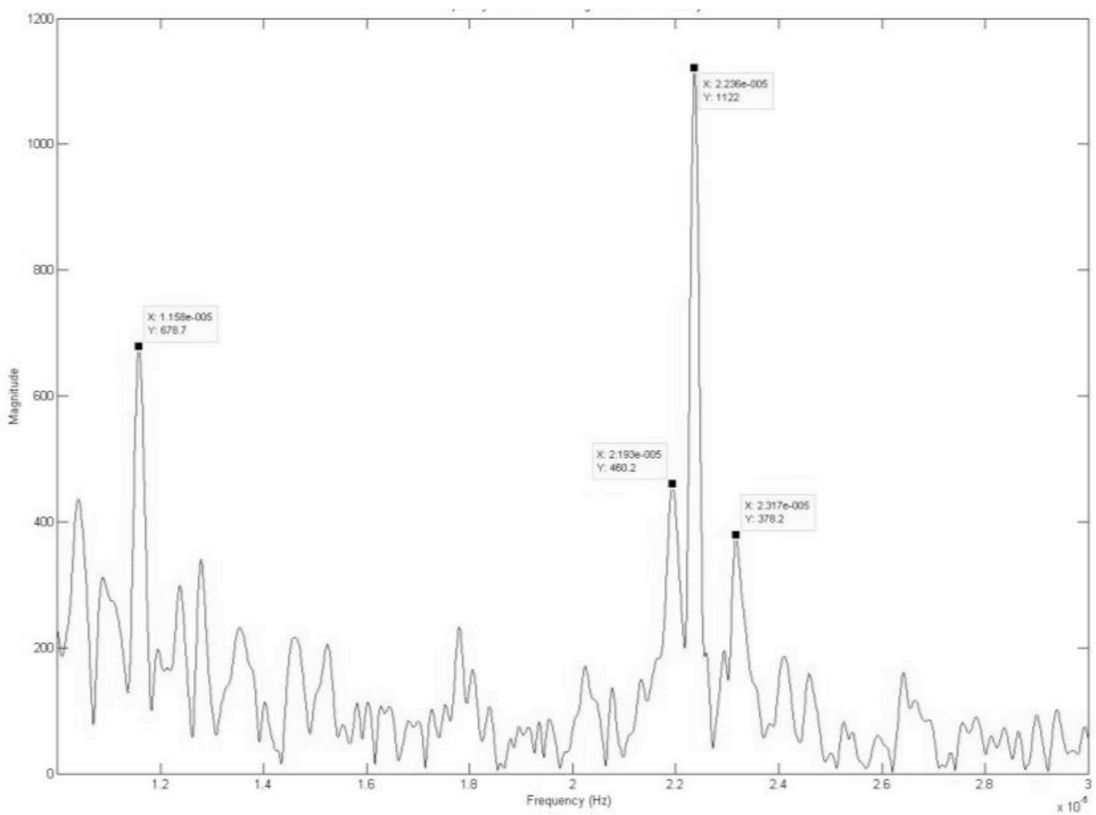




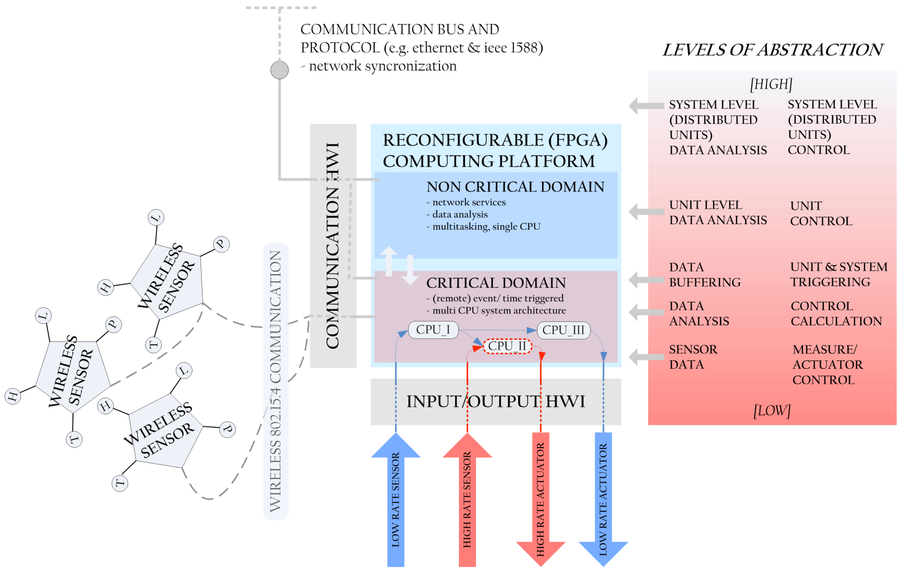
it's alive....

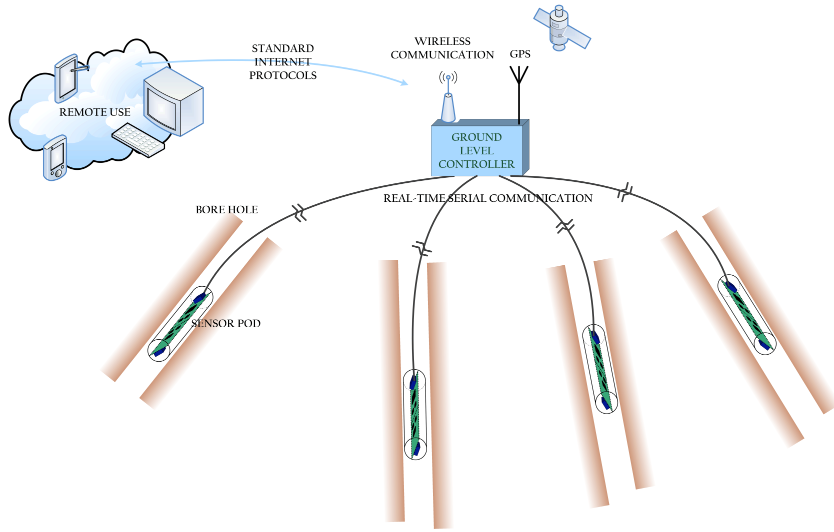


Seismic data from the tri-axial seismometer on the 2000 foot level (610 m) below surface), Homestake/Sanford laboratory, recorded on 12 December 2008 at 18:52 UTC. a) Plot showing numerous events of local origin over a 60 sec record. b) Event with radial distance of approximately 1200 m. y(0) is approximately vertical.



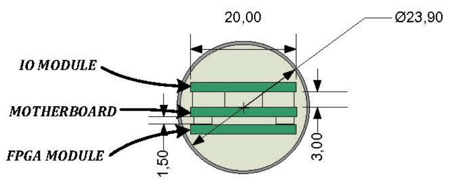
Principal tidal constituents in the semi-diurnal and diurnal bands from windowed FFT of de-trended data collected from one axis of the electrolyte-type (Applied Geomechanics) bubble tiltmeter.

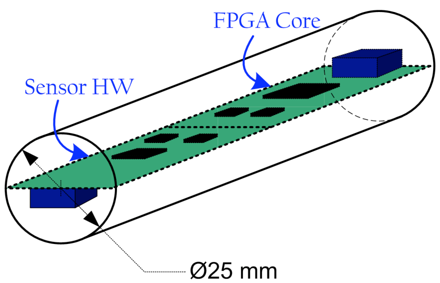


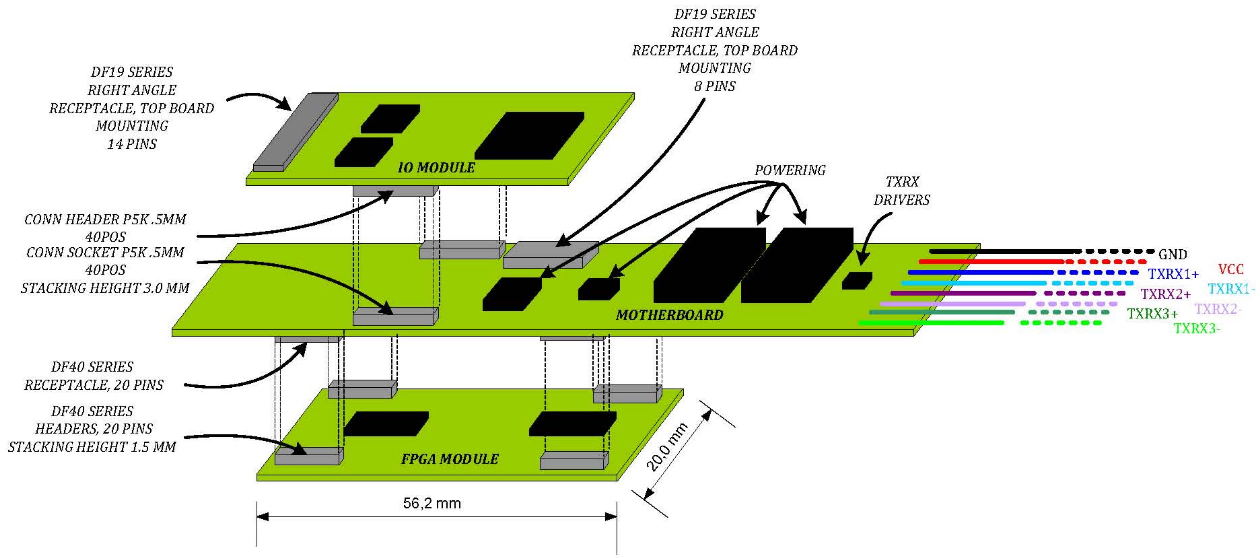


AdapSys – FPGA-based Sensing and Control Appliance

- 24 analog , 256 digital channels - each with real-time machine







Towards the full Homestake Transparent Earth Observatory, **Steven Glaser**, UC Berkeley, **Bill Roggenthen**, SDSMT, **Lane Johnson**, LBNL.

- Doghouse on 4850 and 2000L
- Use existing holes, 75 mm and 150 mm, ream 12 holes 18 m.
- 24 instrument locations throughout the mine
- 0.001 g, 0 ~ 20 Hz, and 0.01 g up to 1 kHz
- Tilt-meter requires 0.5 m^2 concrete pad on a founded-in-rock pier
- Data box is about 300 x 250 x 250 mm
- Roaming installations - small water- & dust-proof storage lockers

Examining seismic sources from micro to macro through multi-sensor inversion. **Steven Glaser**, UC Berkeley, **Lane Johnson**, LBNL, Bill Roggenthen, SDSMT.

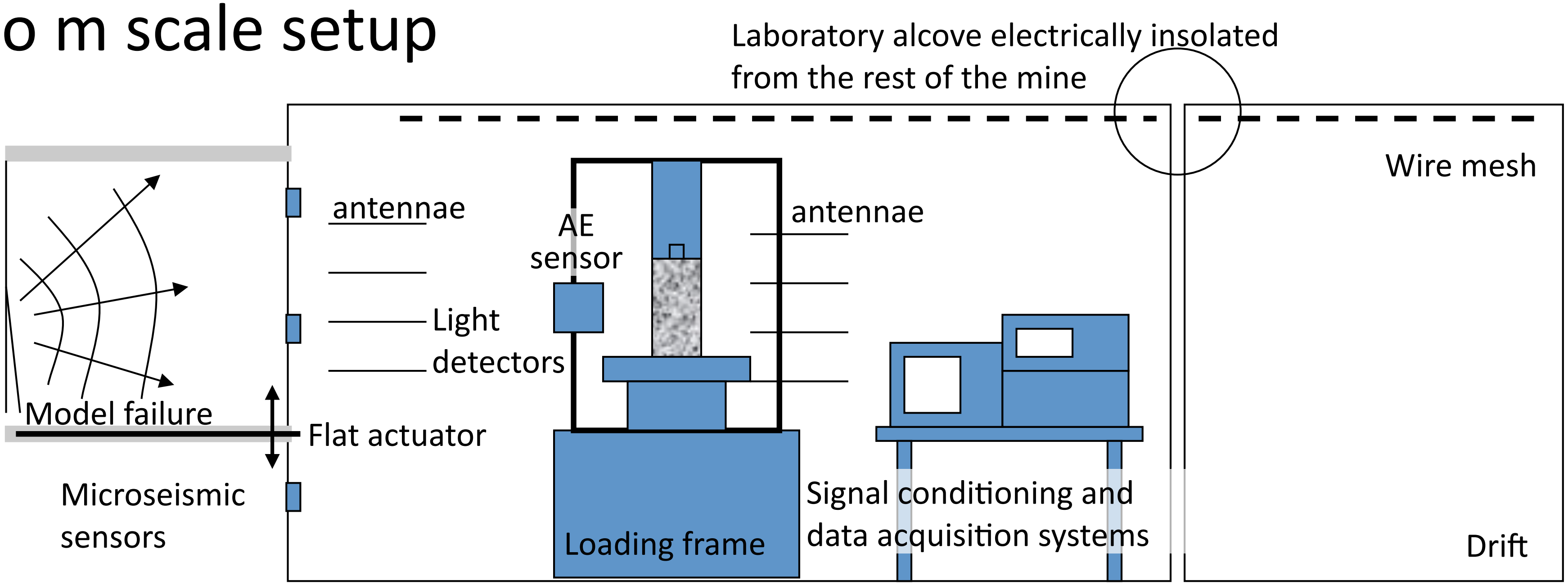
- Off-site computational facility

Valuation of long-period seismic noise at the Homestake.

Lind S. Gee, scientist-in-charge, USGS Albuquerque Seismological Laboratory.

- Test room for broadband seismometers and recorders
- 3 x 3 x 2 m, for two to three people.
- Temp 0°C ~ 40°C, rH < 80%.
- Extreme vibration requirements – no air movement
- Minimal traffic or access by personnel, must be undisturbed for long periods of time
- Vibration-free 0.00001 ~ 200.0 Hz band.
- 0.5 m^2 concrete pad on a well-founded-in-rock pier
- Eqpt. - 350 kg tot. in 10 to 15 boxes, tot. vol. ~ 6 m^3

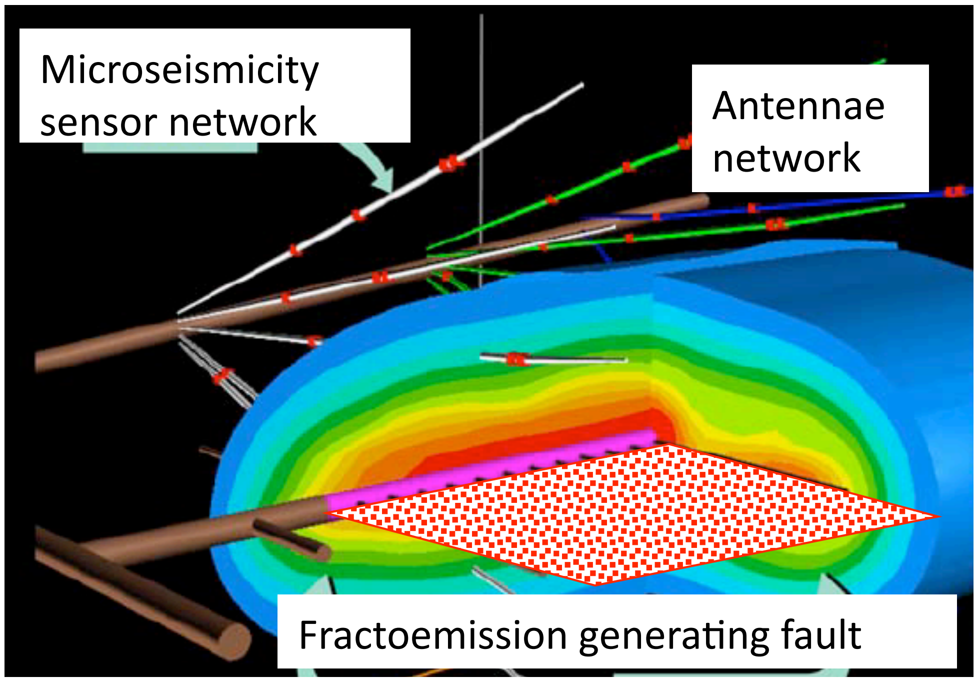
mm to m scale setup



hm to km scale setup

General requirements:
- access to drift at 4850 level
- near any active mining
- away for 660 volt lines
- secure , ~12 ft by 15ft area

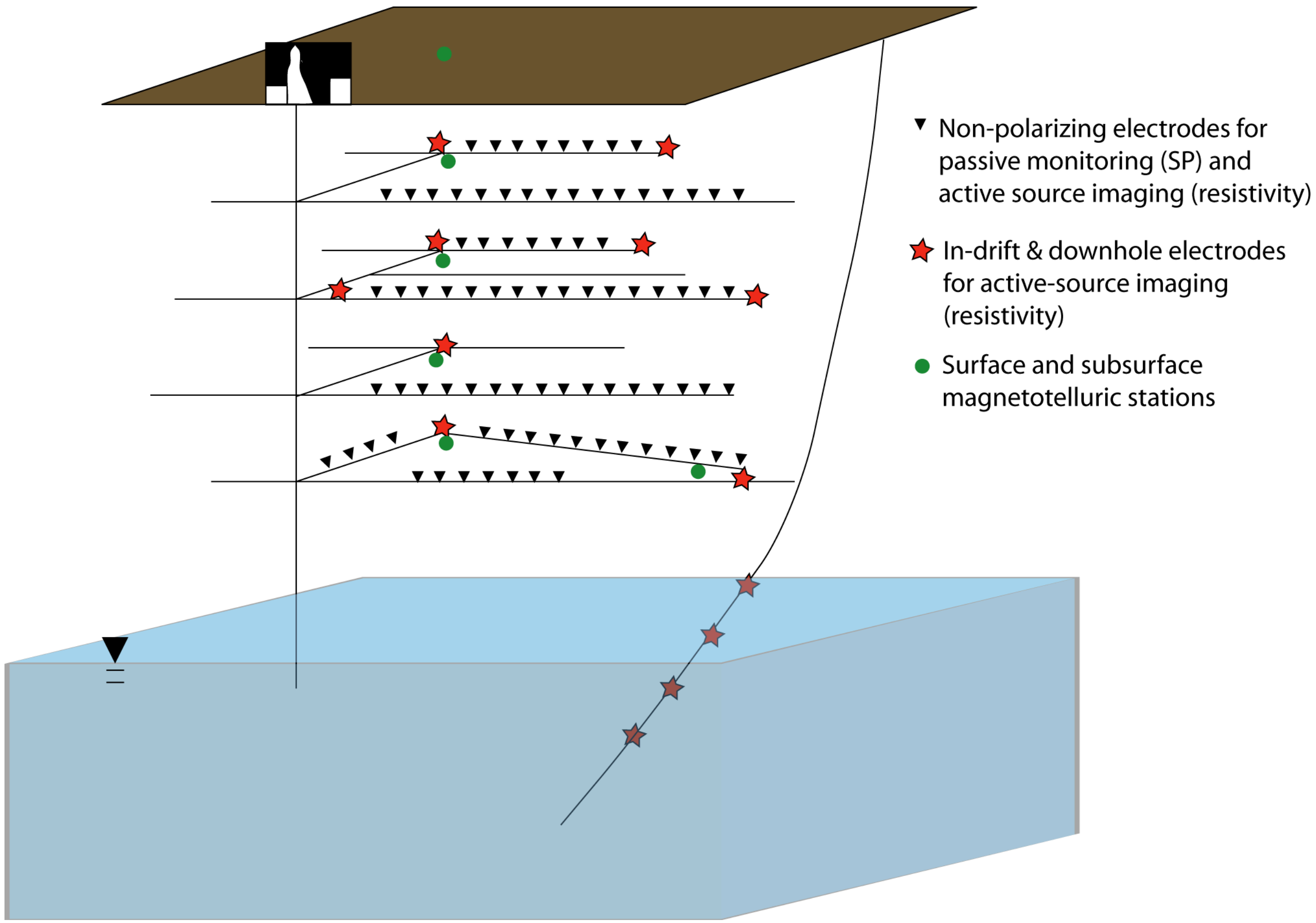
Image: DUSEL
GeoSciences
NSF Report



EM Passive Imaging as a Hazards Assessment Methodology. **Dante Fratta** – University of Wisconsin-Madison.

- 1 doghouse, visited every month or two
- Back wall open to the rock
- House 500 kN test frame, three to four people; for 2.5 years
- 25℃ ~ 30℃; rH < 75%
- Vibrations < 1 kHz must be < 0.5 g.
- 4850 level, within 500 m of the Yates
- Roaming required to deploy EM antennas throughout the mine
- No drilling is necessary since existing boreholes will be used

Proposed electrical & electromagnetic experiment schematic



Paul A. Bedrosian, Burke Minsley, Victor Labson

USGS, Denver

Passive EM studies

Planned Experiment

- Install subsurface magnetotelluric stations at multiple levels.
- Measure vertical electric fields
- Calculation of surface to subsurface transfer functions

Experiment goals

- Examine signal to noise variations with depth
- Examine electrical anisotropy and relation to seismic anisotropy
- Investigate effects of subsurface data and vertical electric fields on structural imaging

Logistical requirements

- Drifts at multiple depths with quasi-orthogonal crossings
- Access to test holes
- Isolation from electrical noise

Passive electrical studies

Planned Experiment

- Electrodes for 3D/4D electrical resistivity & self-potential

Experiment Goals

- Image electrical properties on multiple scales
- Monitor dewatering processes
- Integrate monitoring with other geophysical activities

Infrastructure

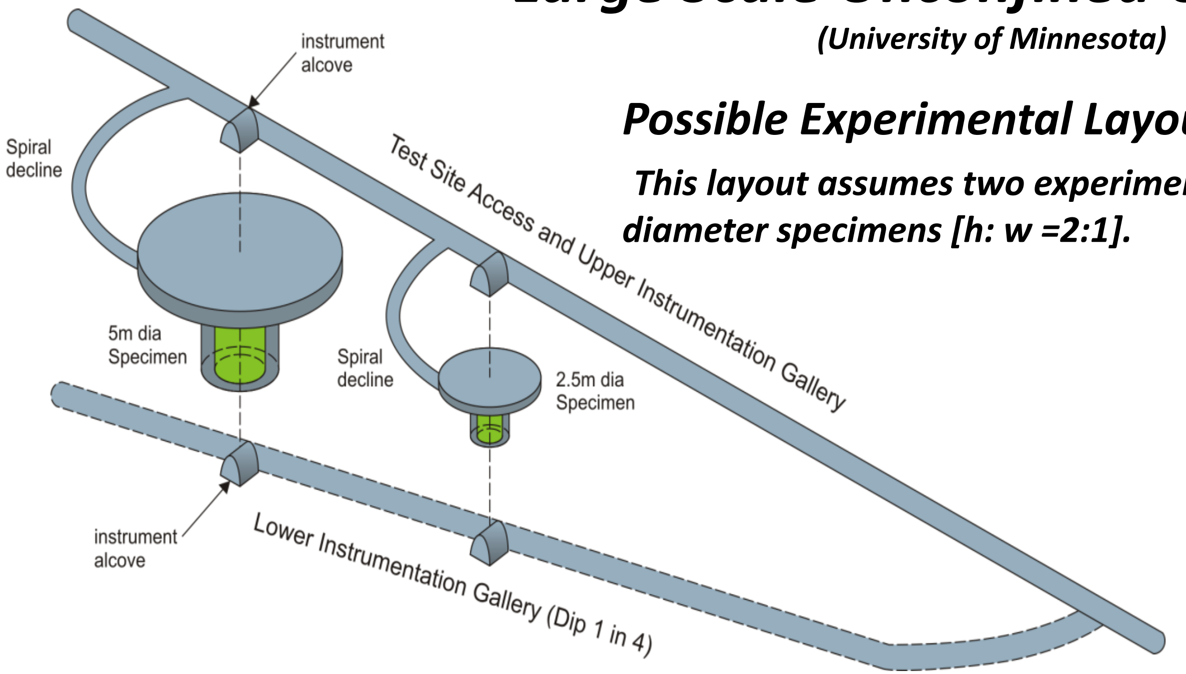
- Multiple drifts, semi-permanent arrays
  - Electrodes may need to be drilled into rock & grouted
  - Electrodes must be connected by wires (across levels)
  - Ideally away from as much infrastructure as possible
  - Downhole source electrodes placed into existing boreholes if possible
- Semi-permanent data acquisition unit
  - Needs to be connected to electrode arrays

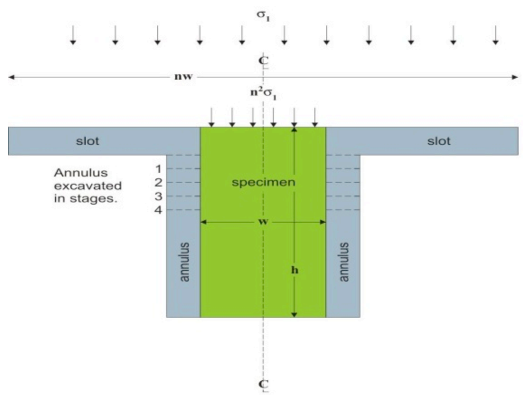
Large Scale Unconfined Compressive Test

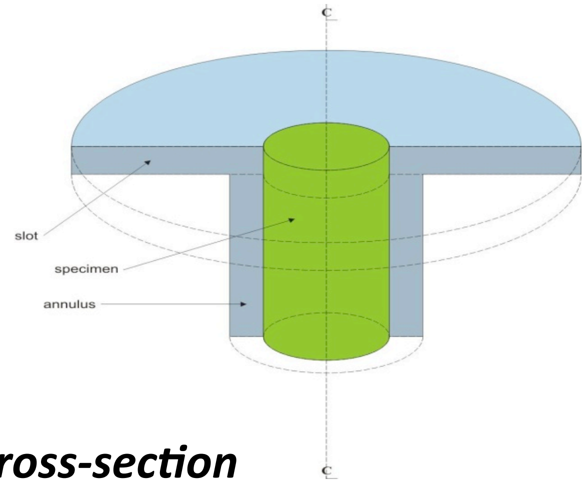
(University of Minnesota)

Possible Experimental Layout – Schematic.

This layout assumes two experiments; 2.5m, and 5.0 m diameter specimens [h: w =2:1].

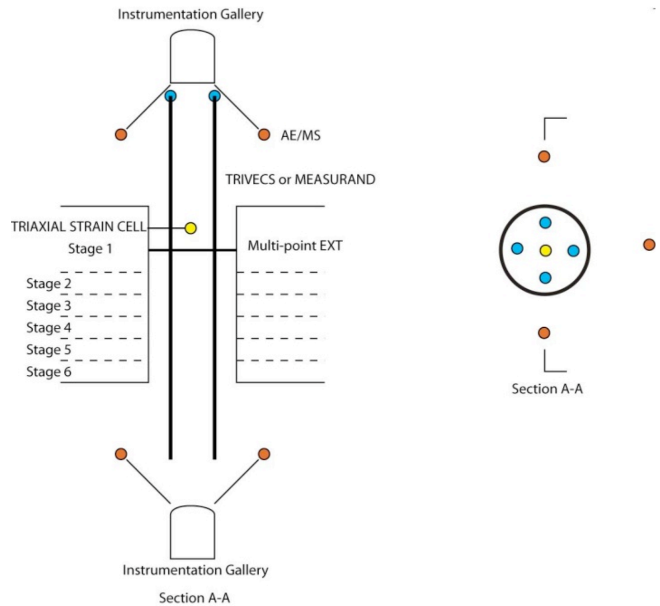






Cross-section

Height of slots and width of annulus will depend on equipment available; 'specimen' could be square; final height: width ratio of ~2:1 would be reached in stages; etc.



Instrumentation layout-schematic. (vertical section)

Freund Group resources needed at DUSEL

1. Active experiment using expanding grout to stress rocks, primarily to measure infrared light emission. Additionally charge motion, surface potential, ULF electromagnetic fields, chemical evolution, and other measurands will be characterized.

- The use of "Bustar" expanding grout simplifies logistics of rock-stressing experiments, no hauling and rigging of large hydraulic pistons needed
- Site resources required:
  - Deeper site located far from electromagnetic interferences.
  - Standard jackleg-drilled holes the rock face, vertical or downward-sloping.
  - Stable piers and mounting for tilt meters.
  - Water to mix grout, estimated 50 liters/month.
  - Possibly liquid nitrogen, estimated less then 10 liters/month when taking data.

2. Passive experiment to observe charge migration beneath thunderstorms

- Site resources required:
  - Site located as close to surface as possible, possibly more than one level.
  - Standard jackleg-drilled holes the rock face, horizontal and level.
  - Vertical and horizontal arrays of holes in the the rock face.

3. Solar-to-crust interaction and ionospheric coupling
  - Research not performed underground.
  - Possibly one or two cubicles for students and computing resources.

4. General resources required for both sites:
  - 110 VAC power 20 Amp service for instruments.
  - Compressed air or nitrogen.
  - 100MB+ Ethernet and connection to WAN.

S-4 Earth Science Teams and Partners

Current Active Partners

- Eric Sonnenthal - THMCB Experiment
- Leonid Germanovich – Induced Fracture Laboratory
- Steven Glaser – Transparent Earth

Future Active Partners

- Larry Stetler - Hydrological and Ground Motion Studies
- Larry Murdoch - Ground water flow system at DUSEL
- Catherine Peters – CO2 Sequestration
- Herb Wang - Fiber-Optic Strain and Temperature Monitoring

ALL experiments are partners of the Homestake Transparent Earth Observatory

Applied Geomechanics tiltmeter data in time and frequency domains