Deep and Ultra-deep Underground Observatory for In Situ Stress, Fluids, and Life

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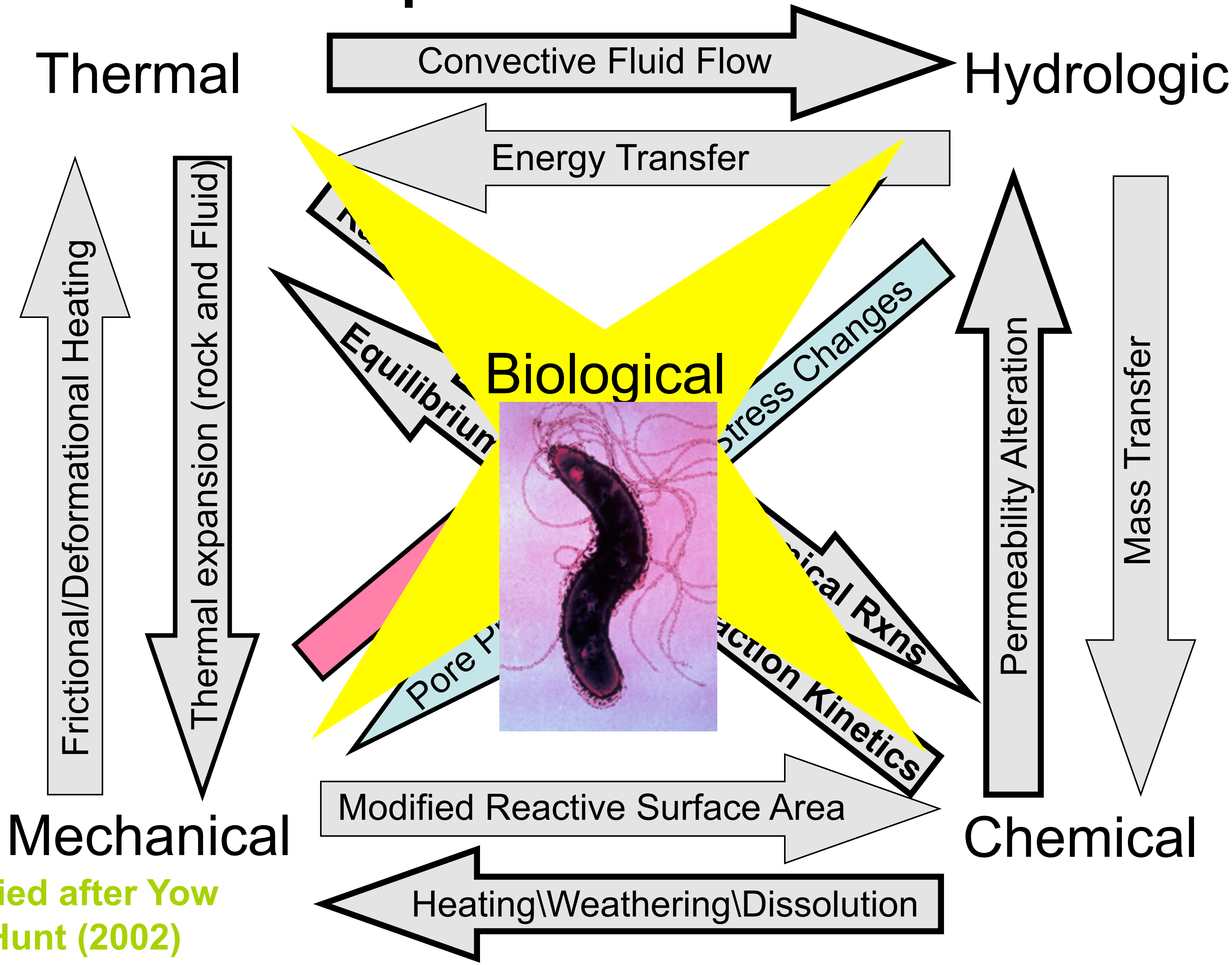
Coupled Processes



Modfied after Yow and Hunt (2002)

Compelling Research Questions Connecting Geomechanics, Geohydrology, and Geomicrobiology

What controls the distribution and evolution of subsurface life?

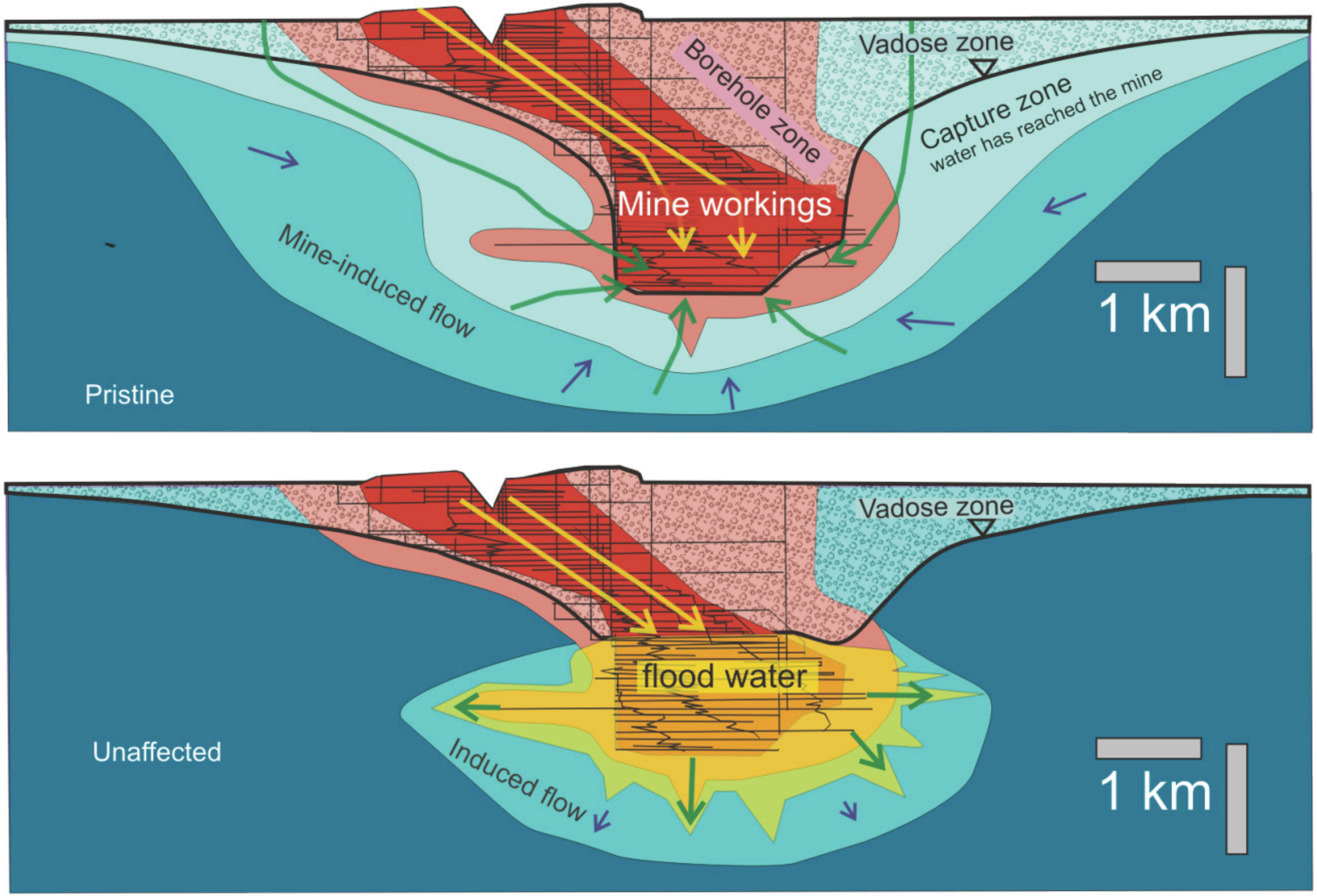
- Do geomechanical and hydrologic factors control the distribution of life as a function of depth and temperature?
- What patterns in microbial diversity, microbial activity and nutrients are found along this gradient?
- How do state variables (stress, strain, temperature, and pore pressure) and constitutive properties (permeability, porosity, modulus, etc.) vary with scale (space, depth, time) in a large 4D heterogeneous system: core – borehole - drift - whole mine - regional?

Why DUSEL?

- Scale and Duration of Access
  - A (Lead) window into the deep biosphere
- 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

DUSEL as a Natural Laboratory

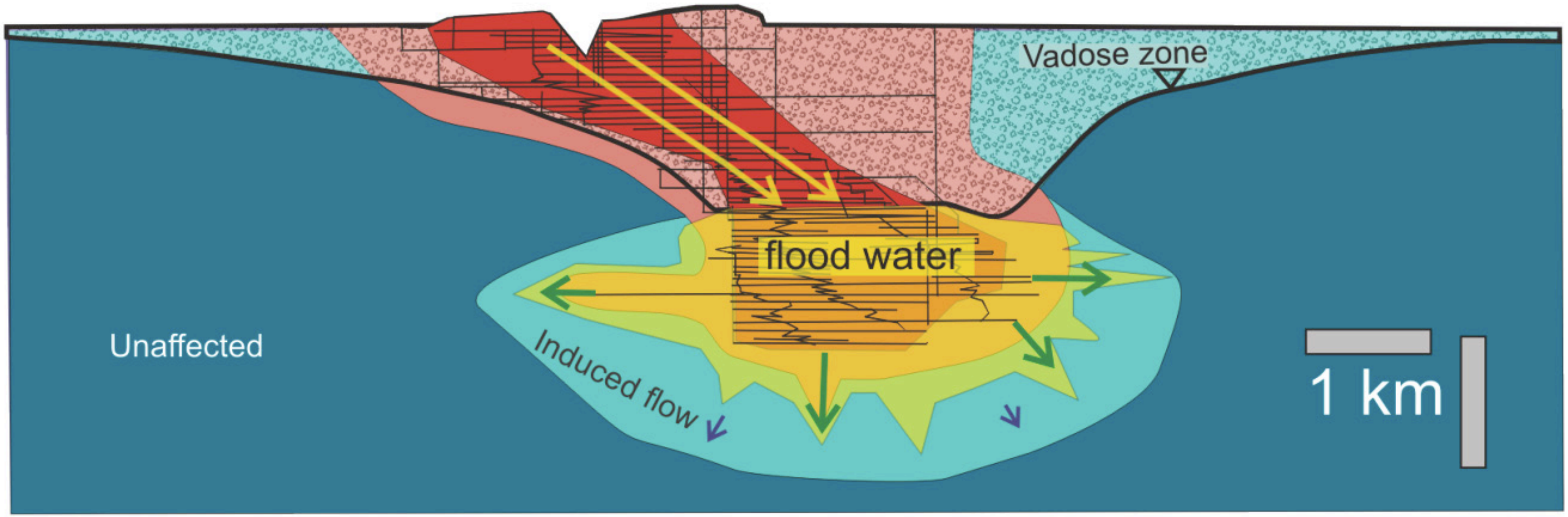
Evolution of Flow System at DUSEL



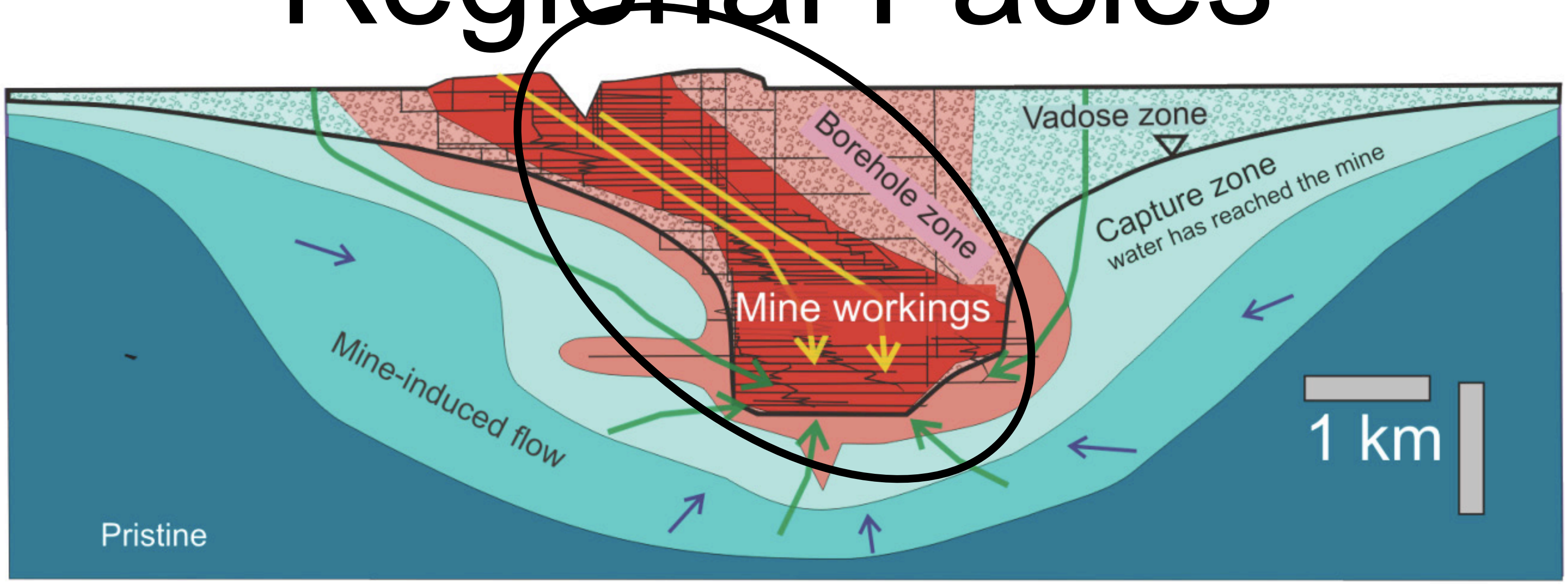
Ecohydrologic Facies

Ecohydrologic facies at DUSEL - distinct zones which have the essential characteristics to support life

These span a range of scales from a regional distribution of conditions spanning many km to local conditions covering 10s to 100s of m to detailed conditions at scales of 1 m or less.

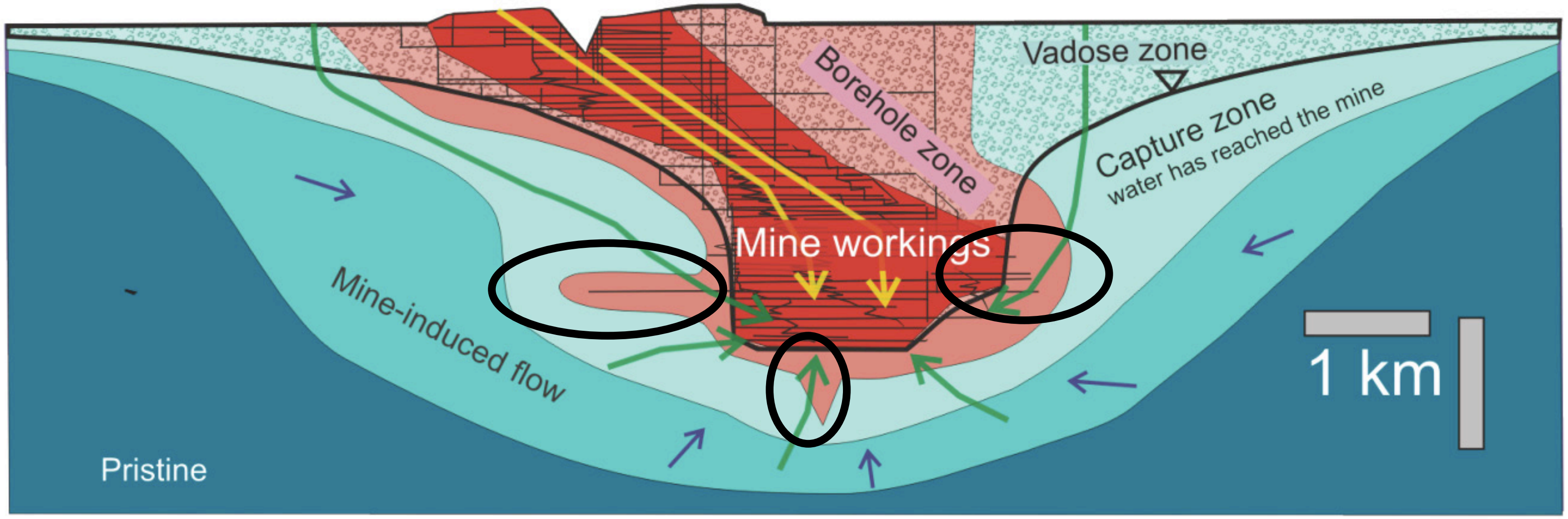


Regional Facies



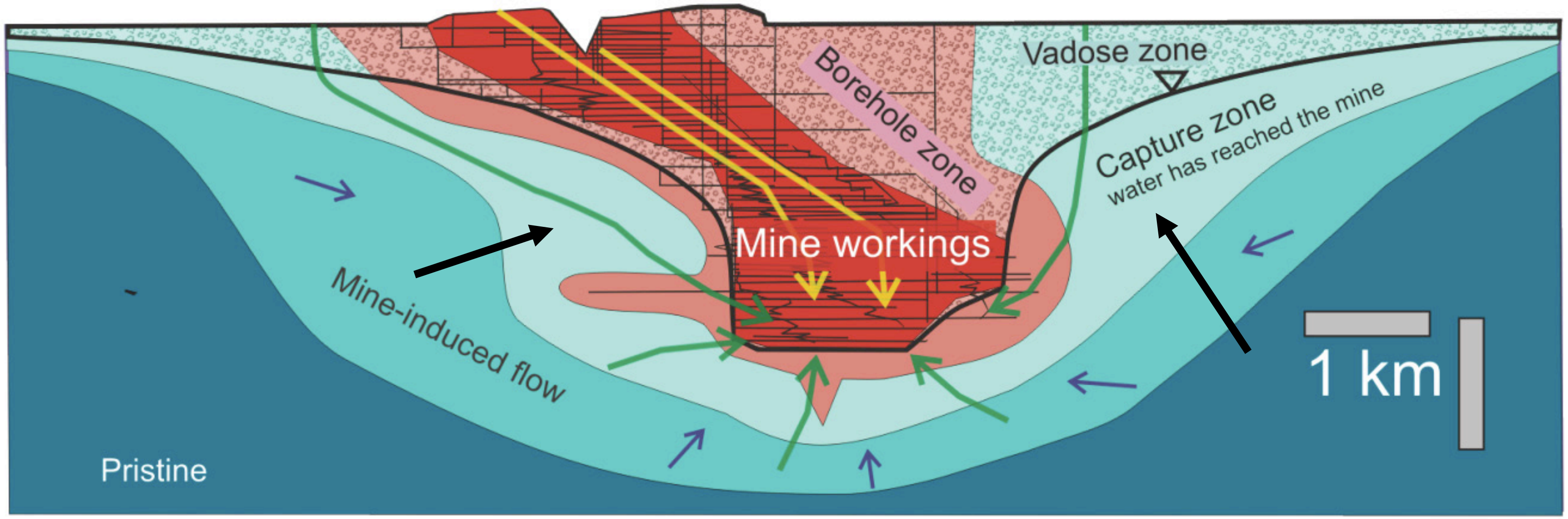
Mine Working Facies The innermost facies is the zone containing tunnels from the mining operation. *Characterized by:* pressure, temperature and compositional conditions that are much different than natural settings at similar depths, provide ready pathways for ingress of terrestrial organisms.

Regional Facies



Boreholes The mine workings facies is enveloped by a zone containing boreholes drilled outward from the workings. *Characterized by:* elevated concentrations of oxygen, or other compounds or organisms from the mine, likely that water flowed from the rock into the mine through many of these boreholes

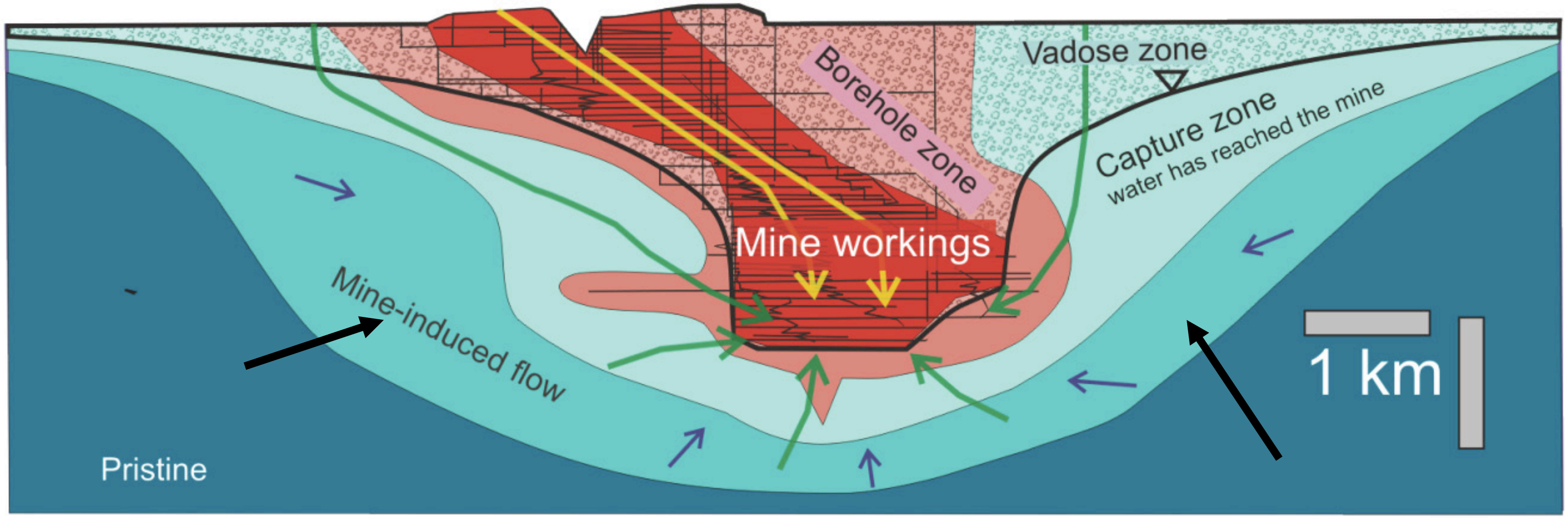
Regional Facies



Capture zone This region includes the original locations of water that flowed into the mine.

Characterized by: Extent and distribution depends on distribution and of fractures in the host rock. One pore volume of water has been exchanged through the capture zone during operation of the mine.

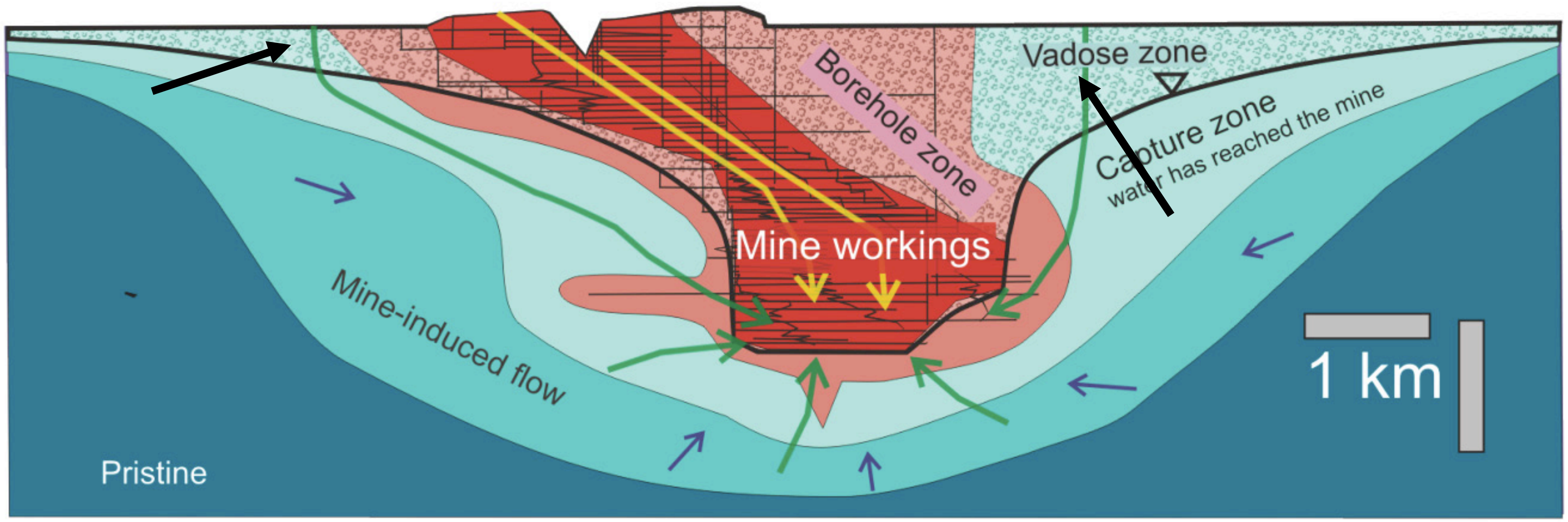
Regional Facies



Mine-induced saturated flow The capture zone is enveloped by this zone

Characterized by: water has moved great distances as a result of pumping, but has not reached the mine

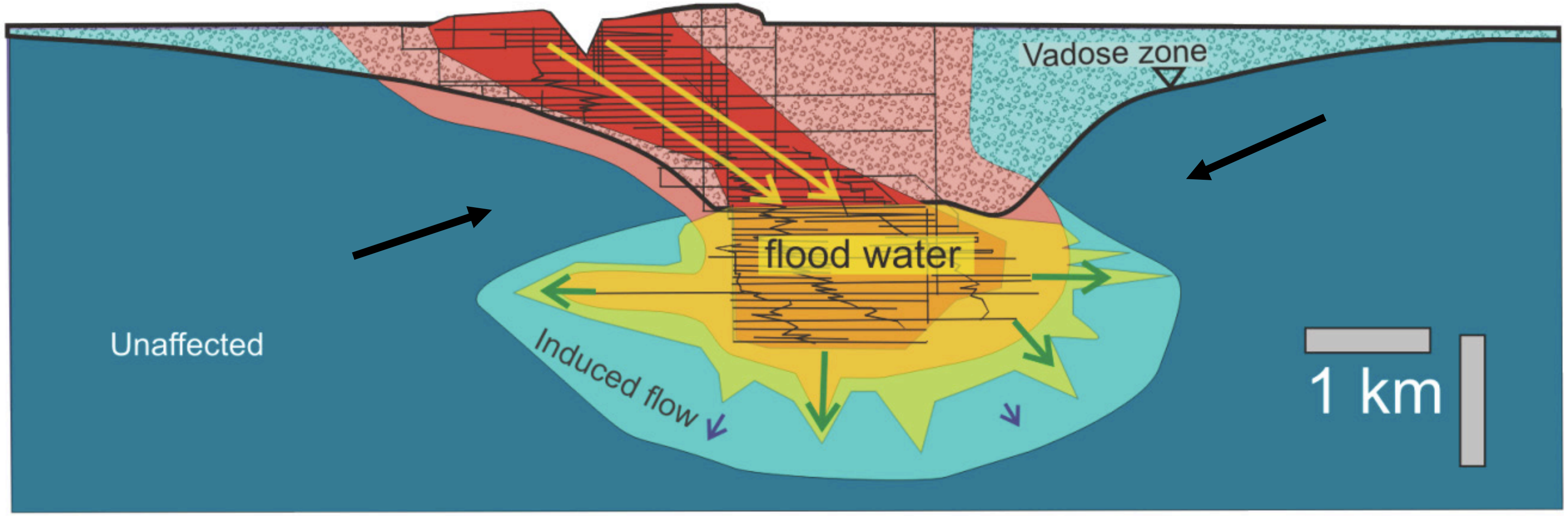
Regional Facies



Vadose zone Pumping has has drained pores/fractures in the vicinity of the mine.

Characterized by: a change in saturation that will likely have affected microbial communities. The vadose zone can be more than a km thick

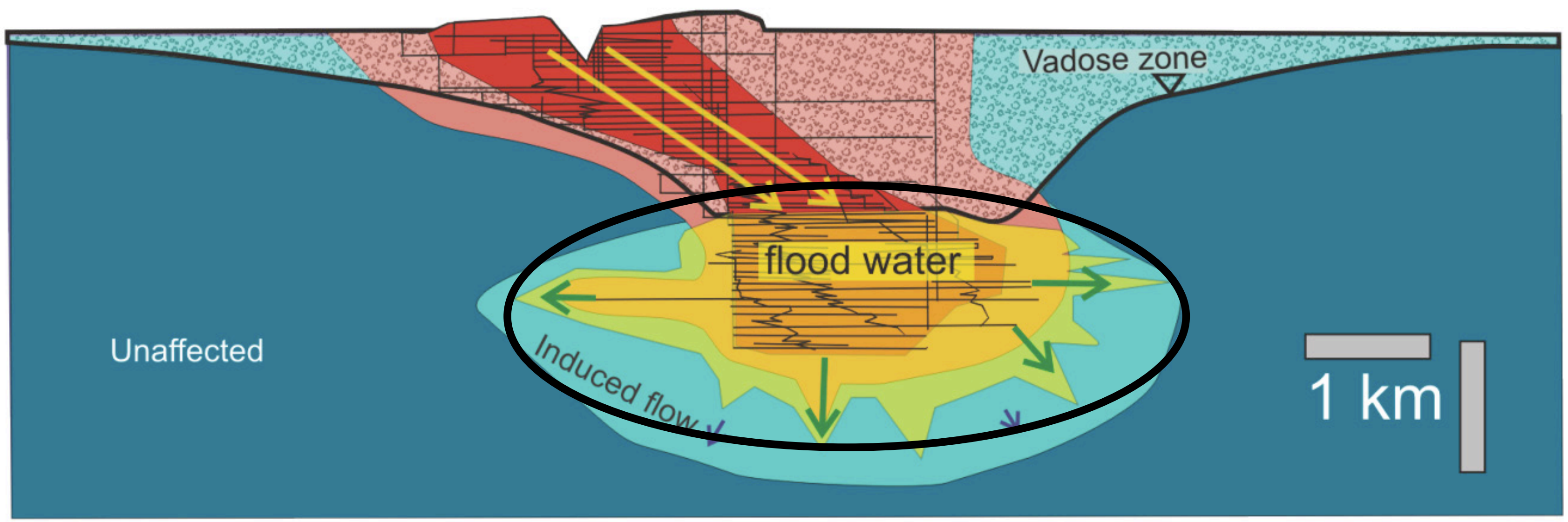
Regional Facies



Pristine Outer regional facies is the area where flow paths induced by mining are small and ignorable. The effects of the mine can probably be ignored in regions where the water has flowed a distance < 10 percent of the distance to the mine.

Characterized by: Fluids and microbial communities corresponding to natural conditions

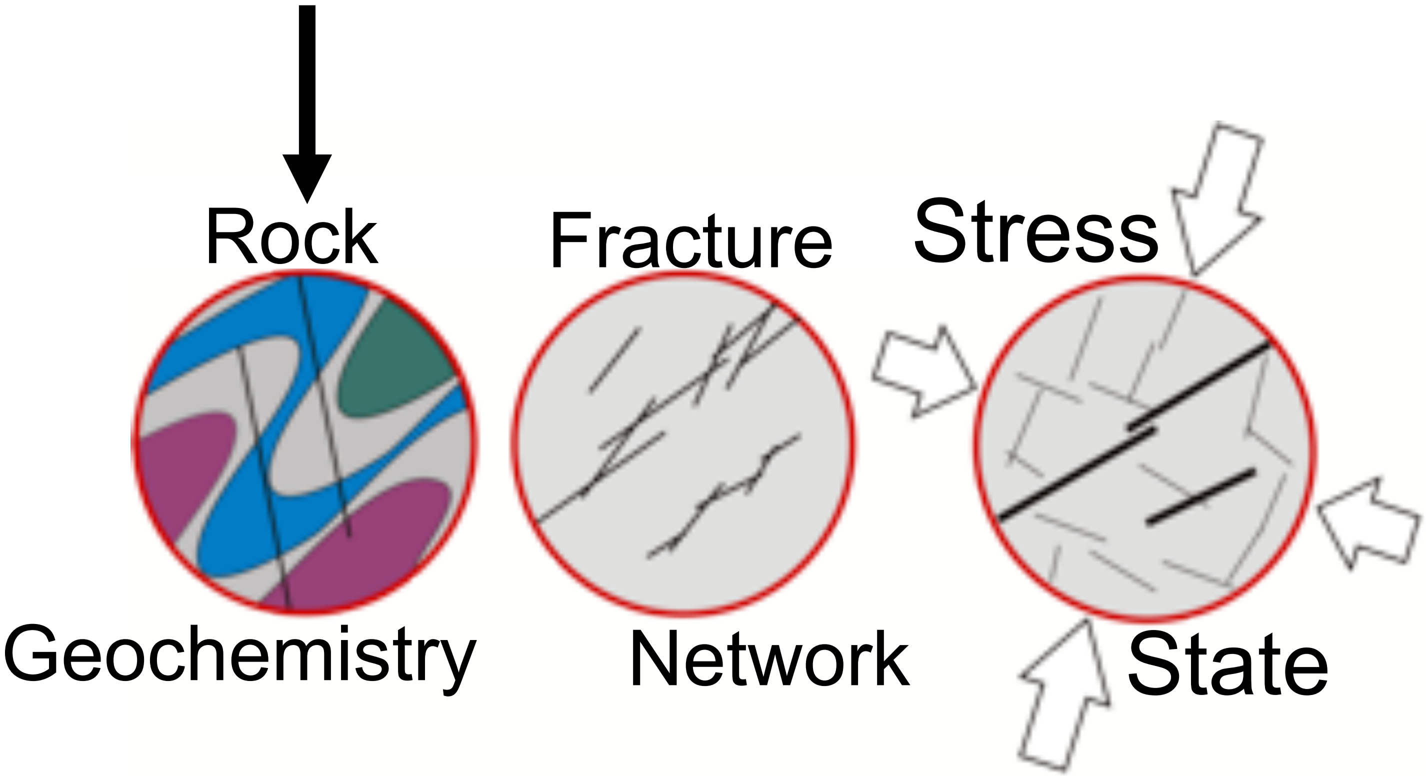
Regional Facies



Flooded The flooding event that occurred after mining ceased increased hydraulic heads by more than 1 km. *Characterized by:* infiltration of mine water, will be important to several investigations

Local Facies

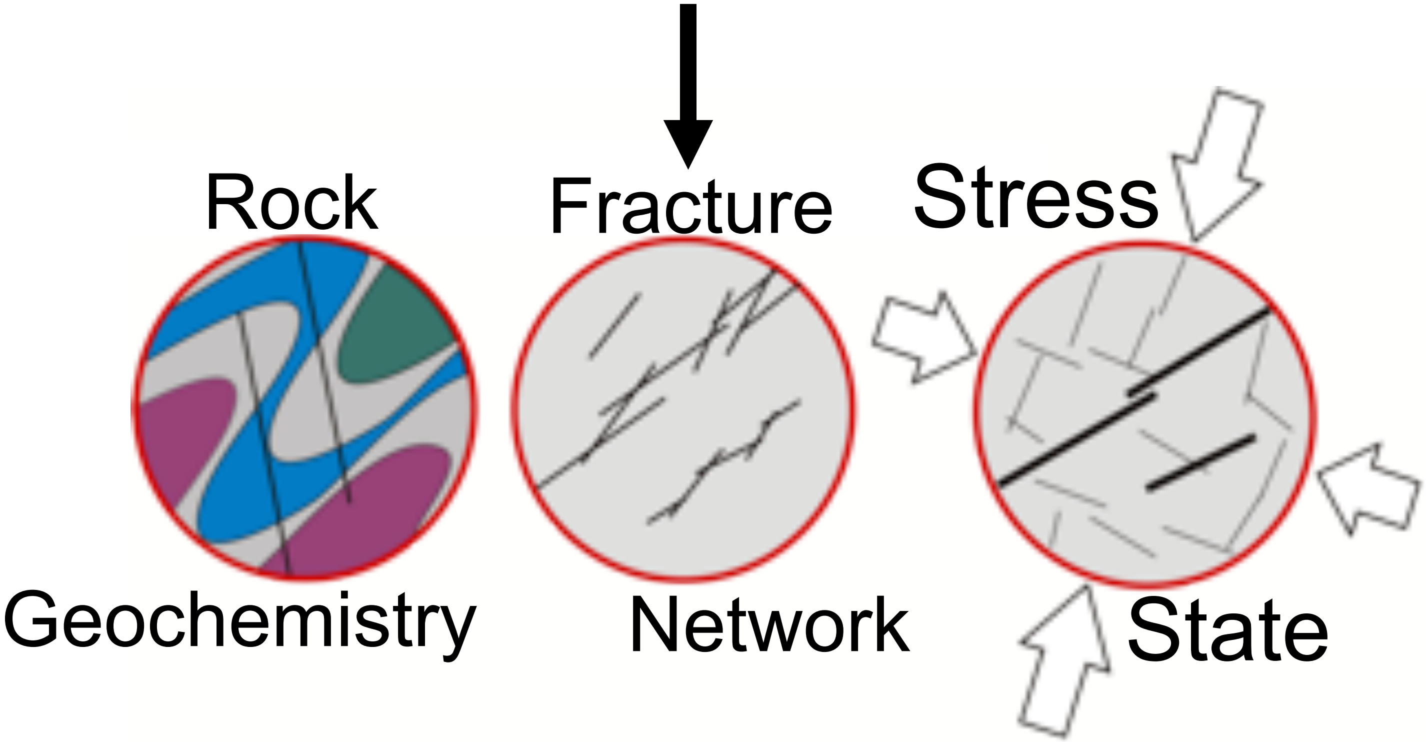
Rock Composition: The folds and broad range of rock types cause the rock composition to vary abruptly. Broad categories of *Characterized by:* felsic, intermediate, mafic and carbonate will be used for preliminary classification based on typical cation availability



Local Facies

Fracture network connectivity: Fractures are known to intersect their neighbors to form networks ranging across a wide range of scales.

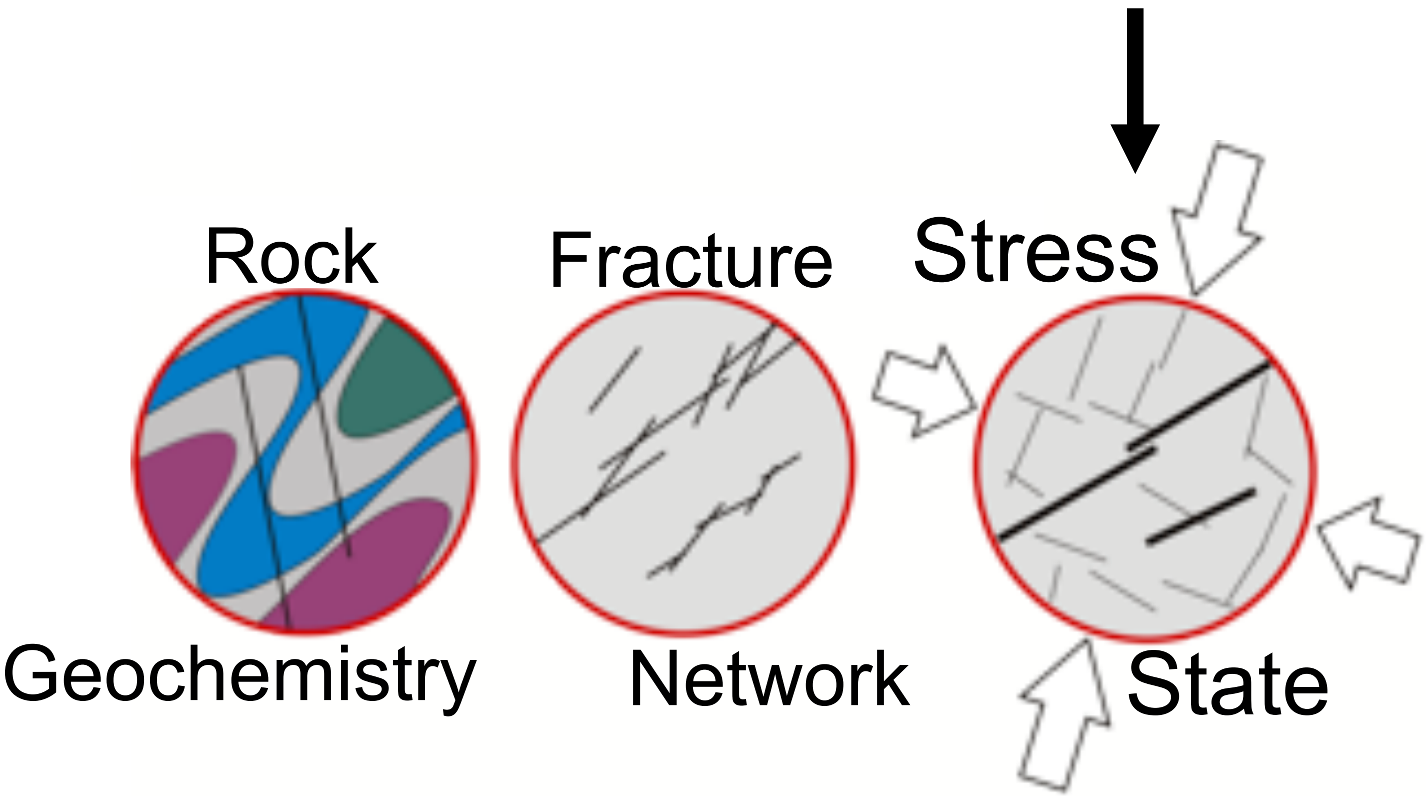
Characterized by: Zones roughly 100 m in maximum dimension, and neighboring zones are poorly connected to one another, has important implications on the extent of microbial communities.



Local Facies

State of stress: Apertures of fractures are strong functions of the magnitudes of the principal stress.

Characterized by: The aperture of fractures that lie in planes of high shear may be dilated as fracture asperities try to slide past one another.



DUSEL: Proposed Experimental Activities

Key Hypotheses

- Biochemical reactions and metabolism are strongly influenced by rock type
- Alteration, disolution, precipitation reactions in rock can be mediated by microbes
- Subsurface ecosystems are bounded by temperature at depth.
- In situ stress affects deep life by controlling the distribution of permeability along fractures.
- The diversity, density, and transport efficiency of microbes increase with fracture connectivity and the scale of percolating fracture networks.

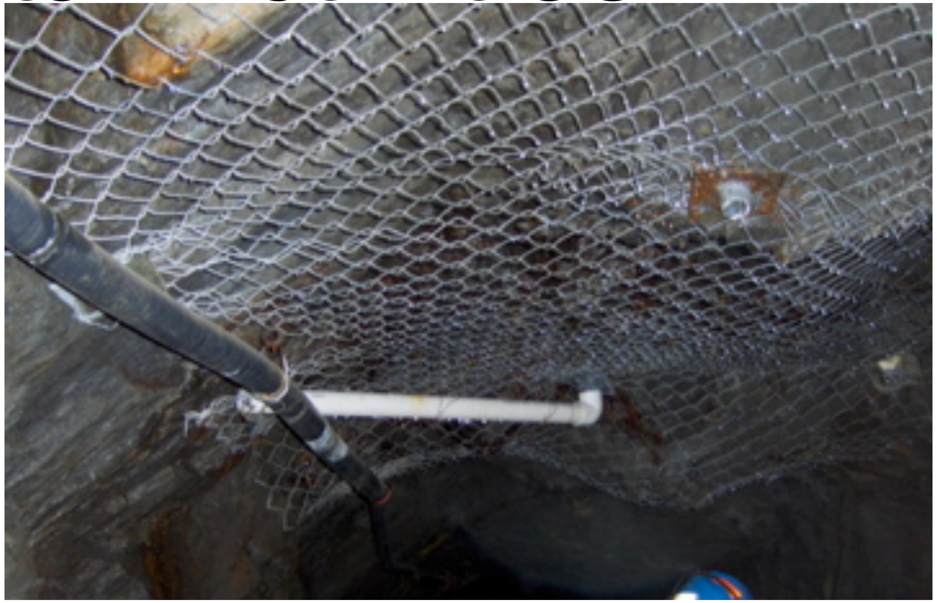
Key Hypotheses

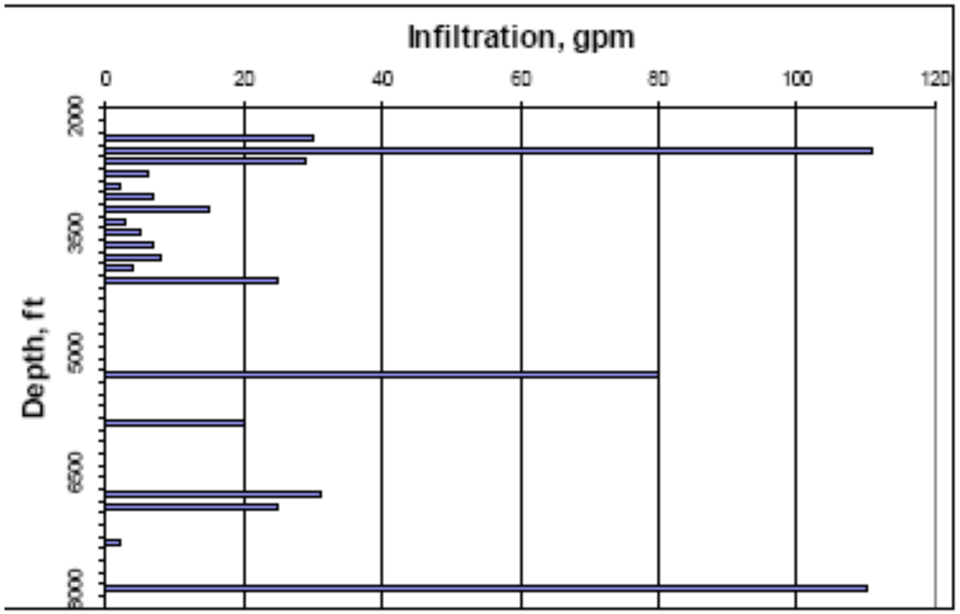
- Microbes both affect the composition of dissolved compounds in ground water, and are affected by the concentration and species of these compounds.
- The transport of microbes in the deep subsurface is controlled by advection in flowing ground water and sorption to pore surfaces.
- The diversity and density of subsurface life are controlled by the flux of mass and heat.
- The scaling of state variables (stress, strain, temperature, and pore-fluid pressure) and constitutive properties (permeability, porosity, modulus, etc.) in a large heterogeneous system can be inferred by evaluating data in core, boreholes, individual drifts, and the entire DUSEL.
- Grouping of environmental conditions into spatial zones, or facies, will provide a construct that highlights processes controlling subsurface life.

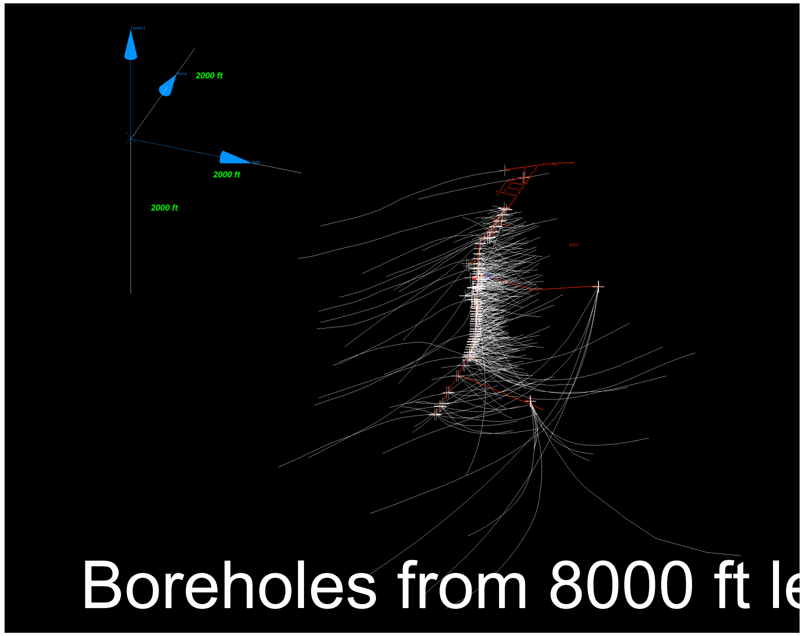
Experimental Activities

Initial Characterization

Spatial Distributions and
Temporal Distributions



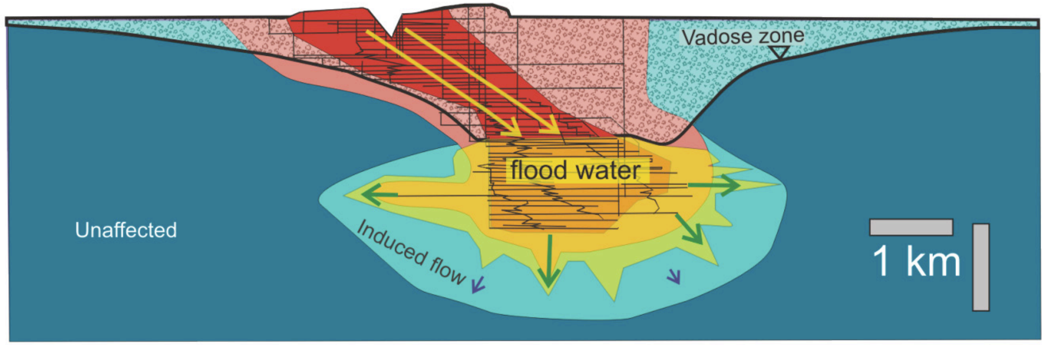




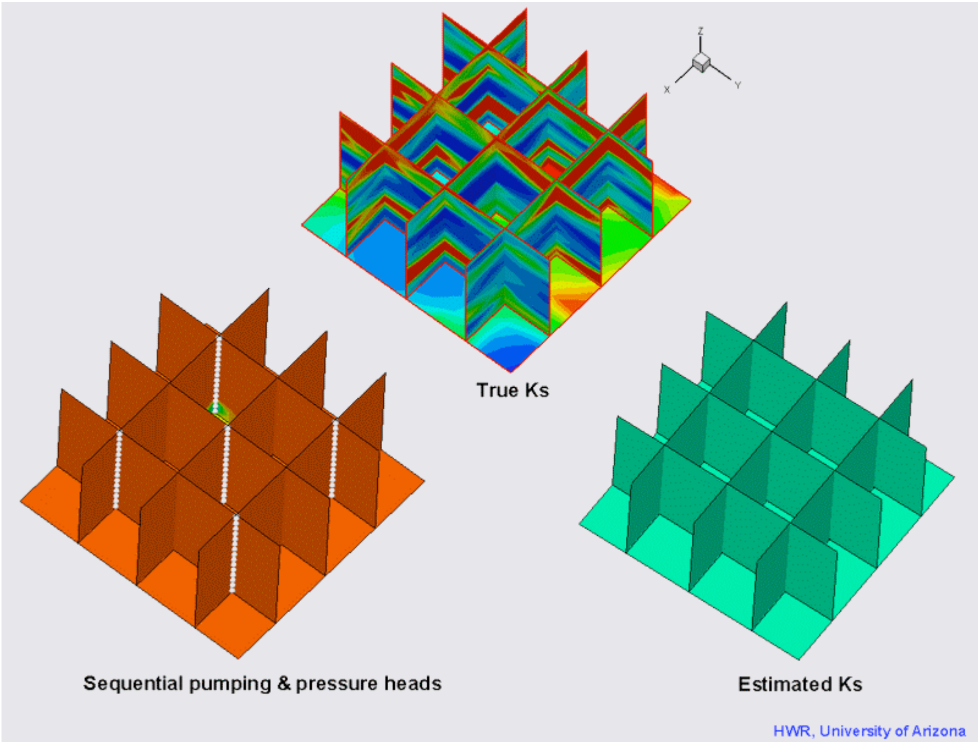
Experimental Activities

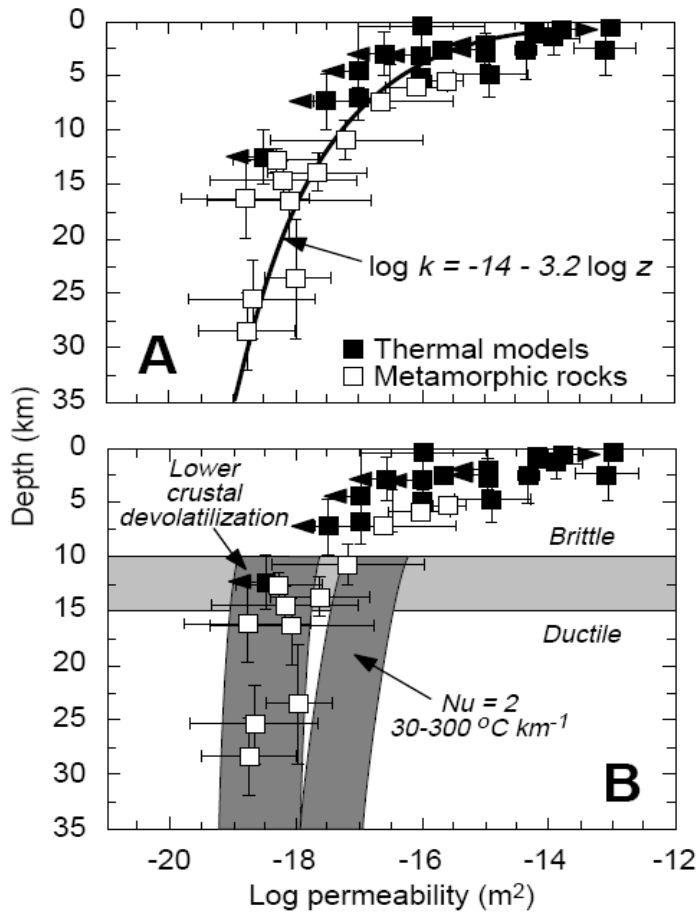
Flow System

Large Scale Tracer Tests



Local-scale tracer tests and Hydraulic Tomography

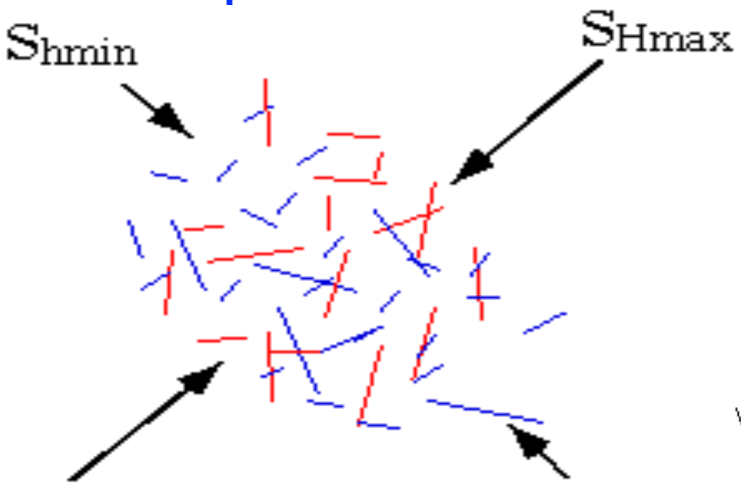




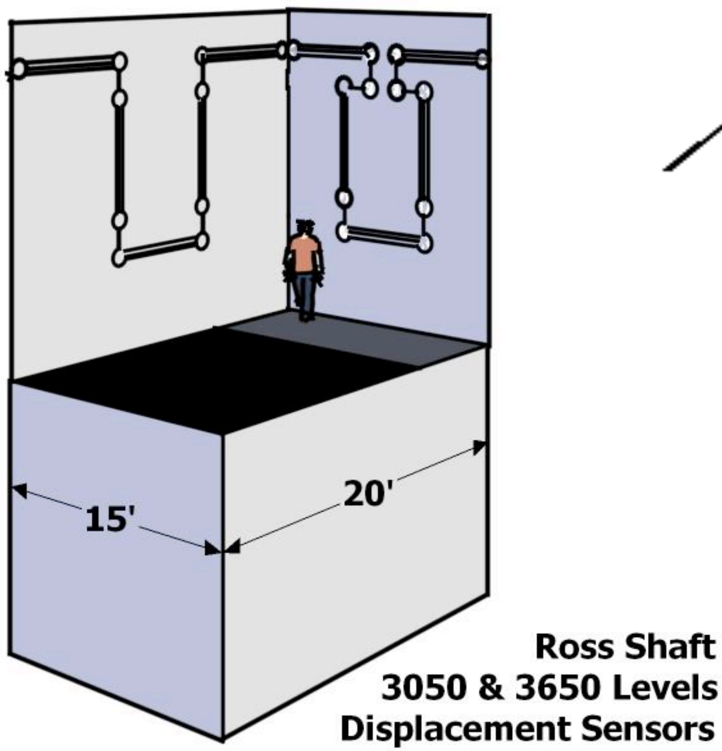
Experimental Activities

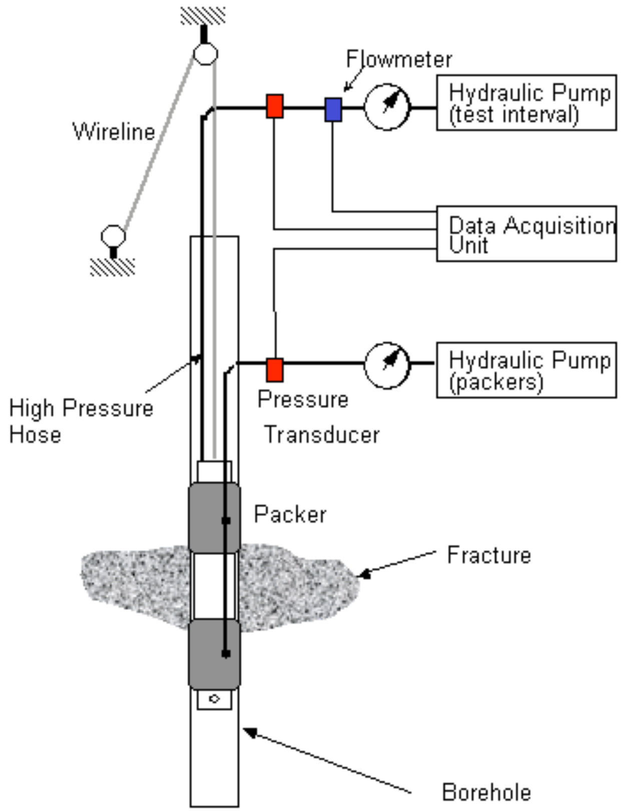
Stress and Deformation

Assess Stress State and Properties



Assess Deformatior





Experimental Activities

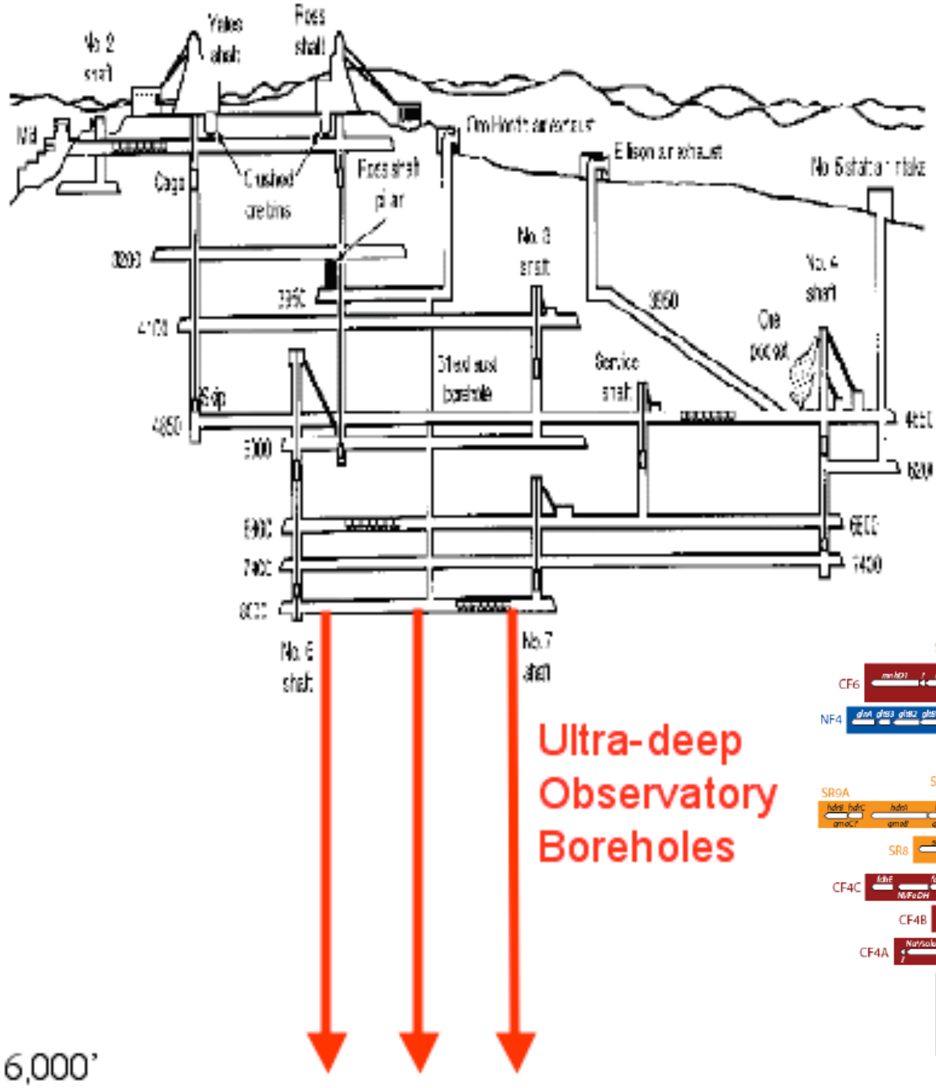
Exploration

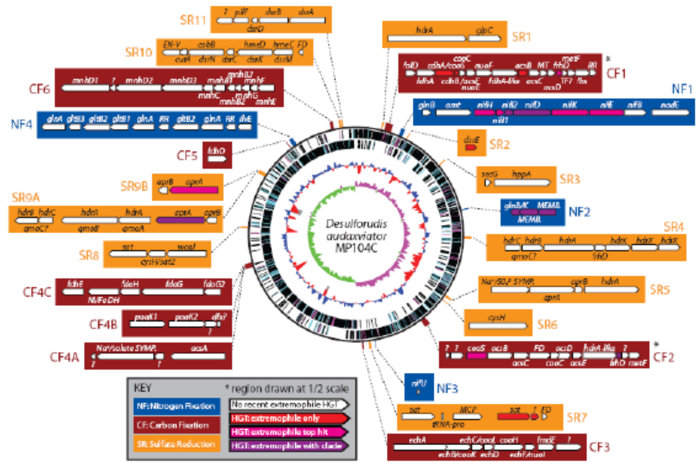
Geothermal gradient: ~22.3 °C/km

0 m 7.5°C

2440 m 62°C

4880 m 116°C 16,000'



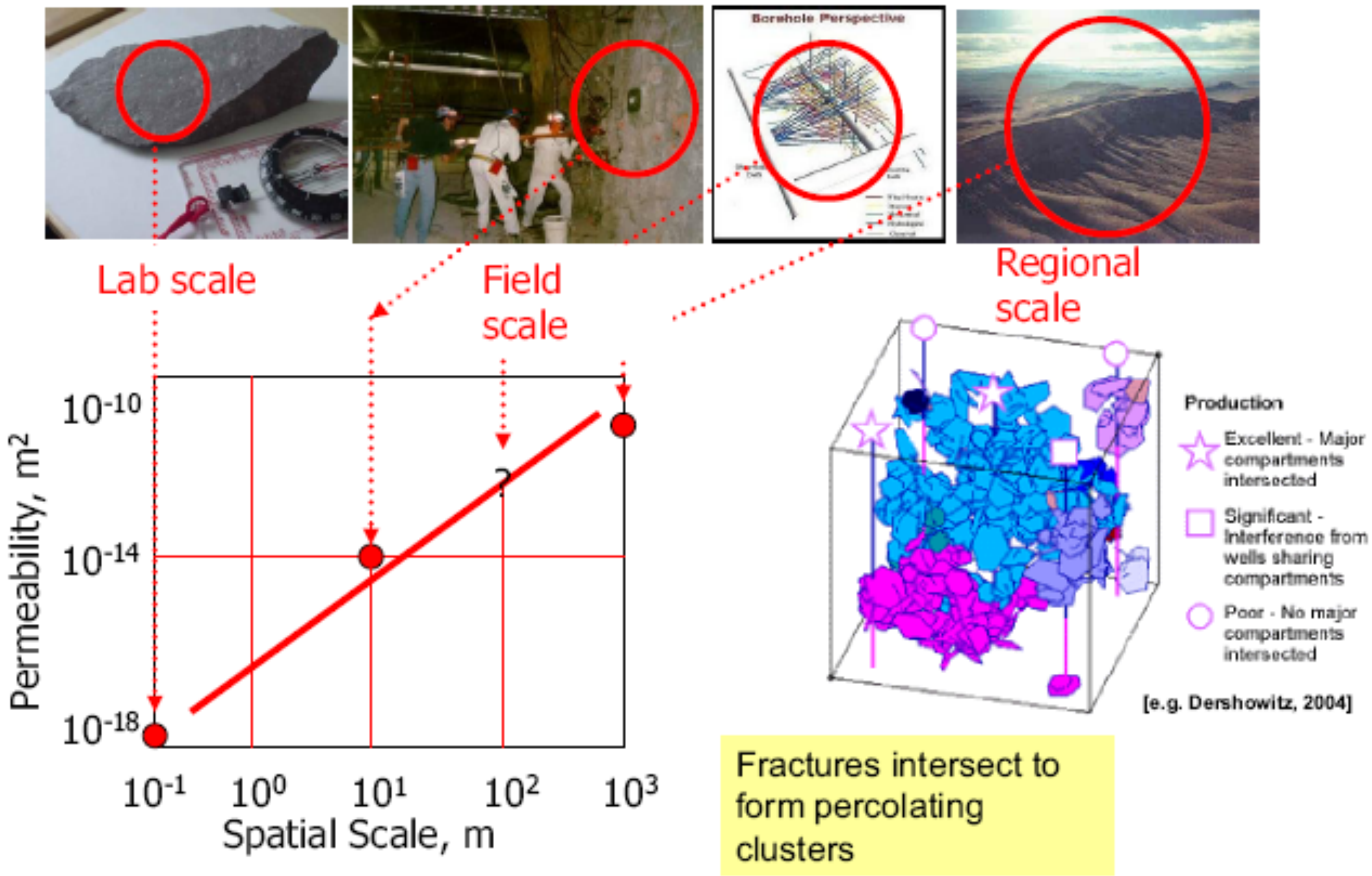


Experimental Activities

Cross Cutting

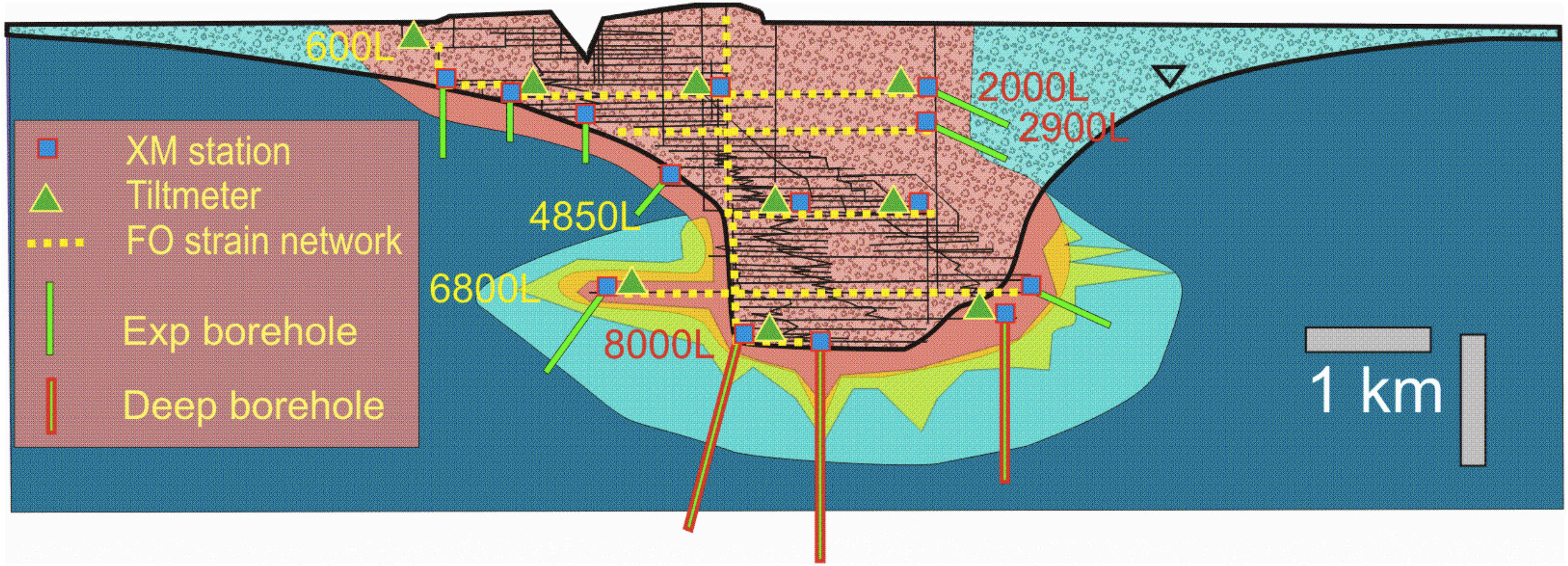
Interdisciplinary Integration

Scaling Laws



DUSEL: The Facility

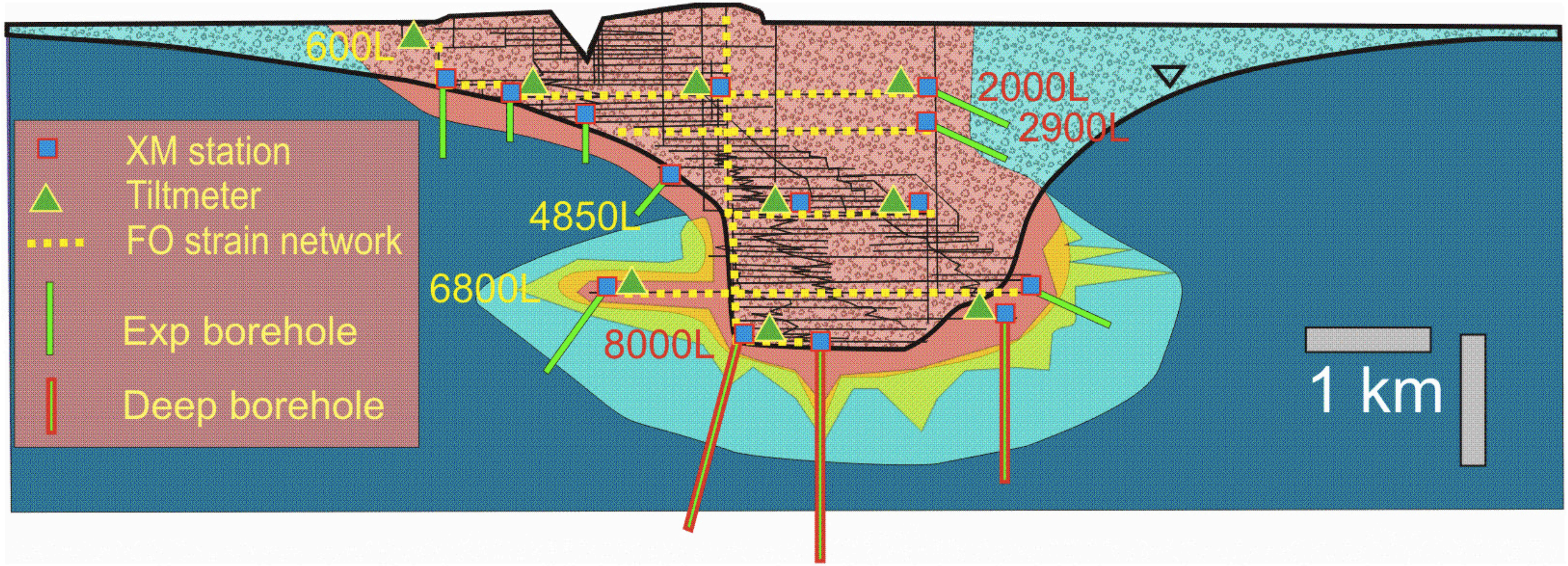
Facility Design



Exploration and Monitoring (XM) stations

Characterize how physical, chemical and biological processes change with time. The stations will consist of sampling and analytical instrumentation deployed at fixed locations. Located at well heads of boreholes, although some may be associated with seeps or related features. The current design consists of 14 XM Stations distributed through the underground workings.

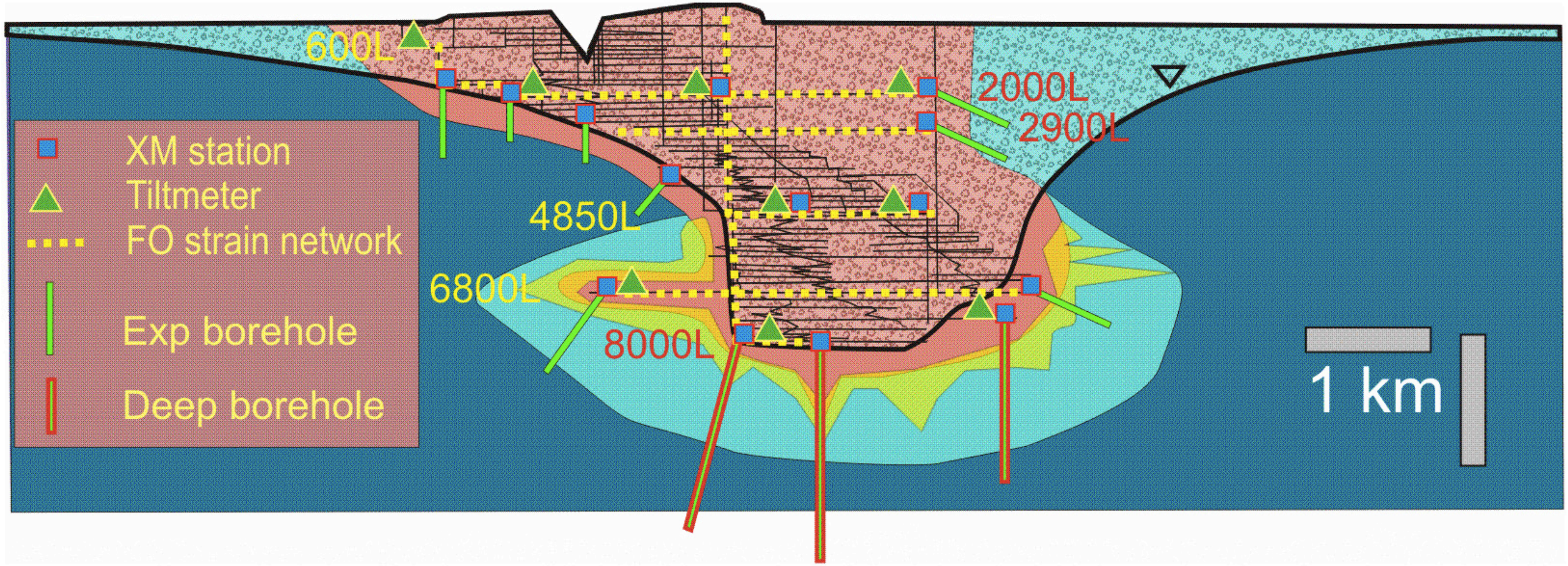
Facility Design



Ultra-Deep Geomicrobiological Observatory

Will probe the lower limits of life in the biosphere. A mobile onsite laboratory (e.g., a MULE) will be used for drill tool preparation, sample handling, etc. Long-term experiments will include real-time monitoring of multiple parameters including pressure, temperature, water, and gas compositions, etc. The laboratory will be capable of performing these experiments under hyperthermic and high pressure conditions.

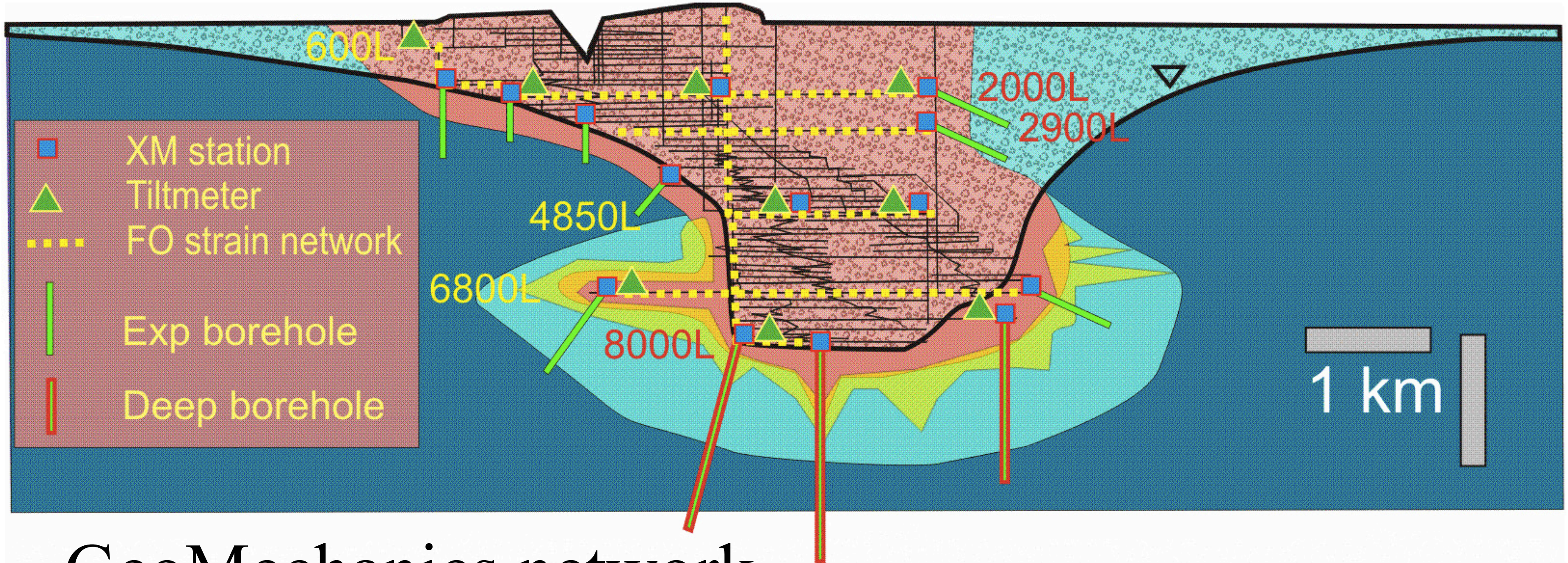
Facility Design



Exploration Boreholes

Constructed to characterize areas that have been unexplored. We are particularly interested in drilling into areas that are relatively unaffected by the presence of the mine because these facies will provide the best window into the natural ecosystem. Some of these boreholes will be placed in the Poorman Formation. The current design includes 10 new boreholes with a total length of 5000 m

Facility Design



GeoMechanics network

Distributed facility will be developed to characterize rock-mass behavior at multiple scales by measuring the deformation resulting from dewatering and excavation. The backbone of the will be an array of continuous optical-fiber displace-ment sensors and tiltmeters covering as many levels, ramps, and sandholes as can be reasonably funded.   A single fiber networks can consist of 50-km of sensing cable, which can be for displacement and temperature.

Education & Outreach Activities

- Experiential learning in deep earth environment for K12, university, and public
- Target local Native American STEM students and develop NSF site Research Experiences for Undergraduates (REU) project on deep ecohydrogeology
- Embed teachers into research activities via NSF Research Experiences for Teachers (RET) projects during summers to develop curriculum
- Develop potential student activities
- Investigate on-line dewatering and climatological data. Monitor stream flow, e.g., False Creek, USGS borehole pressures, surface GPS measurements
- Collaborate with Oregon State University/Portland State University Integrative Graduate Education and Research Traineeship (IGERT) Program on "The Subsurface Biosphere"
- Development of scale model of mine dewatering and flooding with sandbox model where visitors can witness the impact of fluid removal on large volumes of the crust.
- Develop real and virtual underground tours, LIDAR, etc. – student produced video
- Real-time data stream for classroom/visitor center use Visitor Center display

S4 Project Plan

- Refinement of Ecohydrologic Facies
- Prepare WBS
- Compile Preliminary Design
- Solidify Experimental Design
- Design the Facility

Scientific Questions

- What is the relationship between in-situ stress, permeable pathways, and subsurface life?
- How do [subsurface] microbes live in conditions that, from our surface perspective, would seem to make life improbable?
- How have they evolved, isolated for millennia from surface organisms?
- How does porosity and permeability vary as a function of depth and how does this control subsurface coupled processes?
- What controls the heterogeneity and anisotropy of large-scale fluid pathways in otherwise low permeability rock and how does this scale in 3 dimensions?