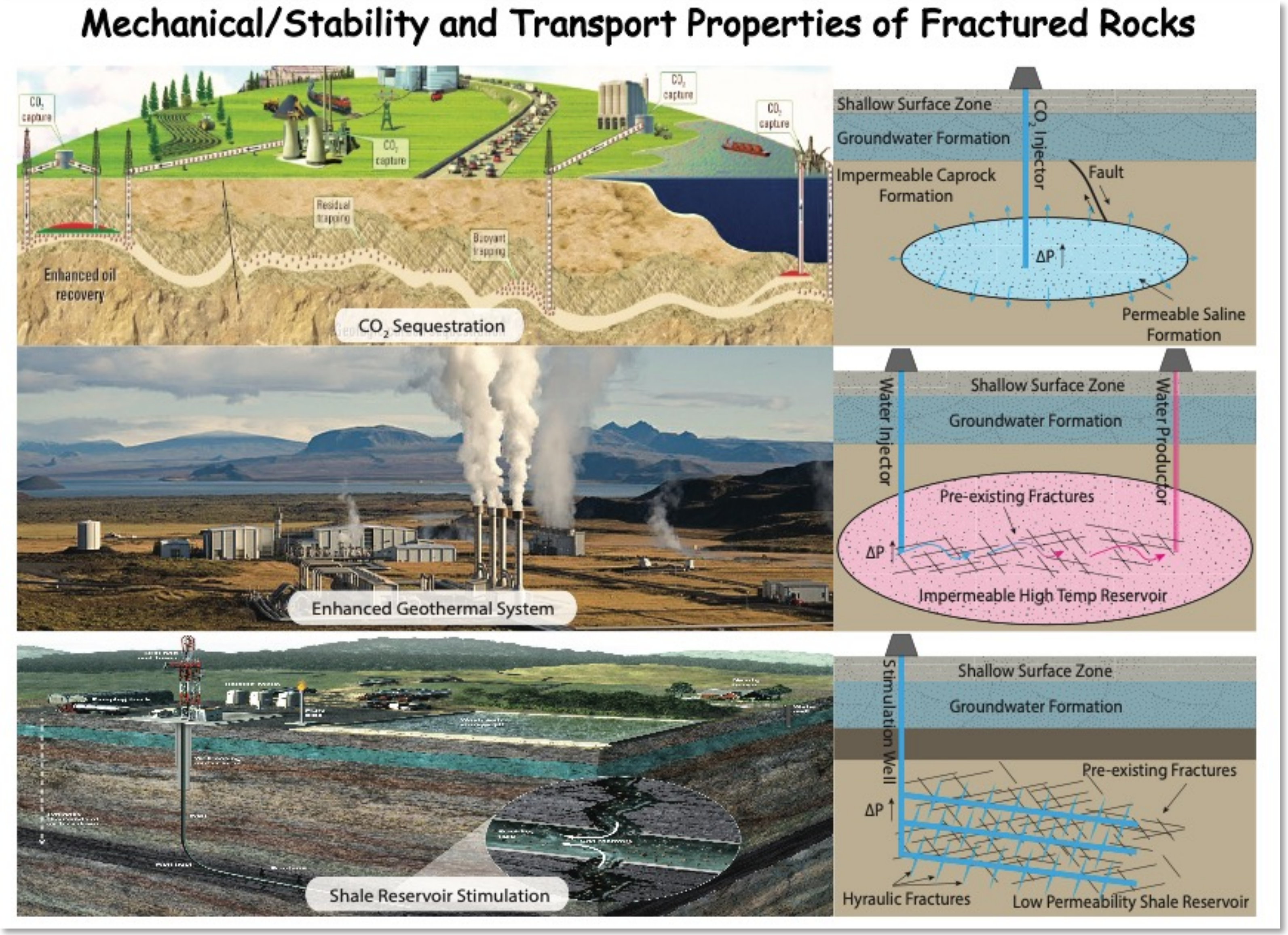
SURF Perspectives in Geosciences and Engineering – Derek Elsworth, PSU



Personal Interests:
Fluids in the crust
Earthquake cycle, IS & TS
Seismicity-permeability relations
Transport in fractured reservoirs
Permeability control

Applied to:
Deep geothermal, CCS, generic reservoirs
Liquid and gas fracturing
Stress measurement
EQ/hydrothermal/volcanic processes

Not:
Underground construction
Tunnelling

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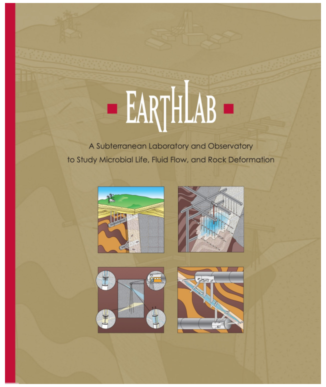
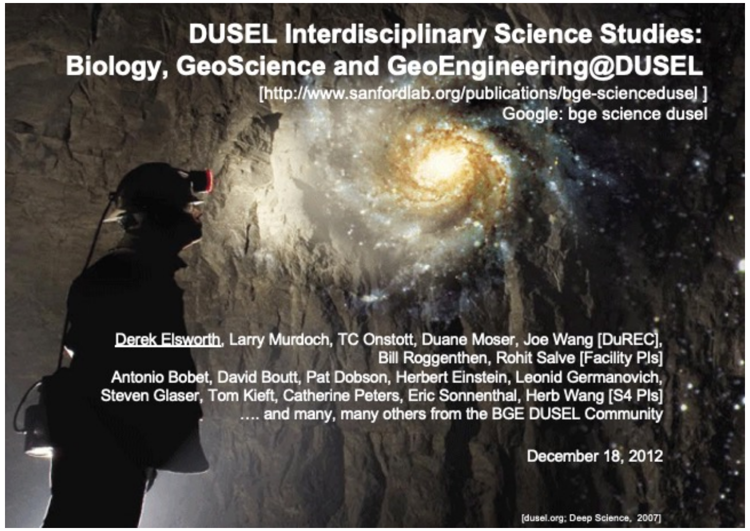
Past as Prologue….. DUSEL 1.0 … to … SURF X.Y



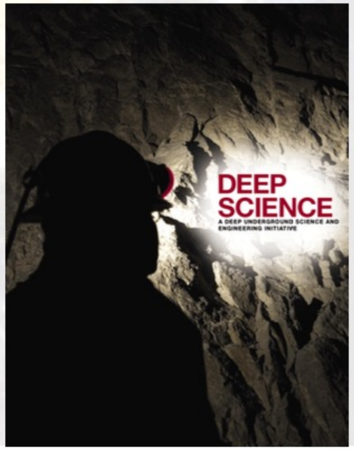


http://www.sanfordlab.org/publications/bge-sciencedusel
Google: bge science dusel
https://slidetodoc.com/download.php?id=315918
Google: dusel interdisciplinary science

Biology, Geosciences, Engineering ….. 2010 DUSEL Grand Challenges

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?



NRC Review - December 14-15, 2010 | 13 | Homestake DUSEL

NASEM-NSF Geosciences & NAE Grand Challenges

A Vision for NSF Earth Sciences 2020-2030
EARTH IN TIME

1. How is Earth's internal magnetic field generated?

Understanding what has powered the geodynamo through time and what controls its rate of change is crucial for understanding interactions from Earth's interior to the atmosphere, as well as the human activities that are impacted by the geomagnetic field.

2. When, why, and how did plate tectonics start?

Plate tectonics produces and modifies the continents, oceans, and atmosphere, but there remains a lack of fundamental understanding of when plate tectonics developed on the Earth, why on the Earth and not on other planetary bodies, and how plate tectonics developed through time.

3. How are critical elements distributed and cycled in the Earth?

The cycling of critical elements essential for geologic processes creates suitable conditions for life and provides the ingredients for materials necessary for modern civilization, yet fundamental questions remain about how elements are transported within the Earth across a range of spatial and temporal scales.

4. What is an earthquake?

Earthquake rupture is complex, and the deformation of the Earth occurs over a spectrum of rates and in a variety of styles, leading Earth scientists to reconsider the very nature of earthquakes and the dynamics that drive them.

5. What drives volcanism?

Volcanic eruptions have major effects on people, the atmosphere, the hydrosphere, and the Earth itself, creating an urgent need for fundamental research on how magma forms, rises, and erupts in different settings around the world and how these systems have operated throughout geologic time.

6. What are the causes and consequences of topographic change?

New technology for measuring topography over geologic to human time scales now makes it possible to address scientific questions linking the deep and surface Earth and urgent societal challenges related to geologic hazards, resources, and climate change.

7. How does the critical zone influence climate?

The reactive skin of the terrestrial Earth influences moisture, groundwater, energy, and gas exchanges between the land and atmosphere, and its influence on climate is therefore a vital component of understanding the Earth system and how it has responded and will respond to global change.

8. What does Earth's past reveal about the dynamics of the climate system?

Evidence of both long-term and rapid environmental change in Earth's history provides key baselines for comparison to modern change, helps to elucidate Earth system dynamics, provides magnitudes and rates of change, and plays a critical role in predicting future change.

9. How is Earth's water cycle changing?

Understanding current and future changes to the water cycle requires fundamental knowledge of the hydro-terrestrial system and how the water cycle interacts with other physical, biological, and chemical processes.

10. How do biogeochemical cycles evolve?

To quantify the role of biology through time in the formation and weathering of rocks and minerals, the cycling of carbon, and the composition of the very air we breathe requires a deeper understanding of biogeochemical cycles.

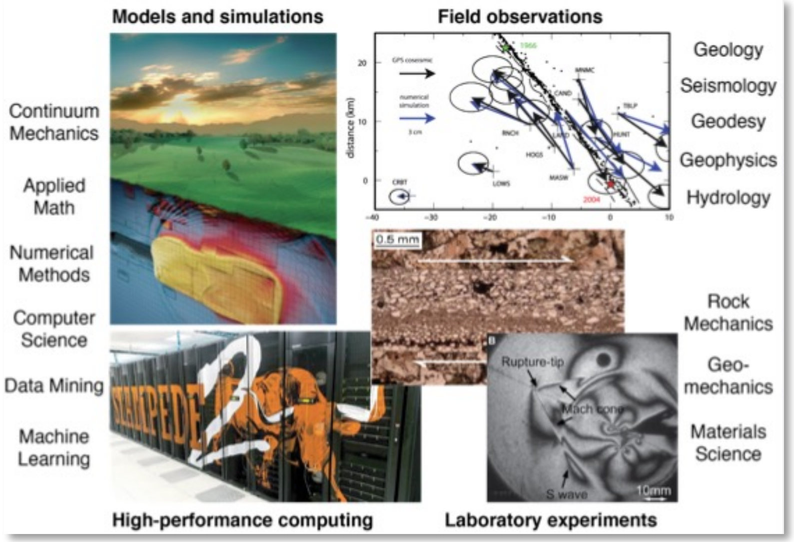
11. How do geological processes influence biodiversity?

The diversity of life on the Earth is a major characteristic of the planet and yet we do not fully know how it came to be. We need to understand how and why diversity has varied over time, environment, and geography, including major events like extinctions.

12. How can Earth science research reduce the risk and toll of geohazards?

A predictive and quantitative understanding of geohazards is essential to reduce risk and impacts and to save lives and infrastructure.

Below from: Lapusta, N. et al., 2019, Modeling Earthquake Source Processes: from Tectonics to Dynamic Rupture, Report to the National Science Foundation.



Attributes of SURF for BG&E Grand Challenges

Pro

Large Spatial Scale – Access to heterogeneous/opaque block at km-scale

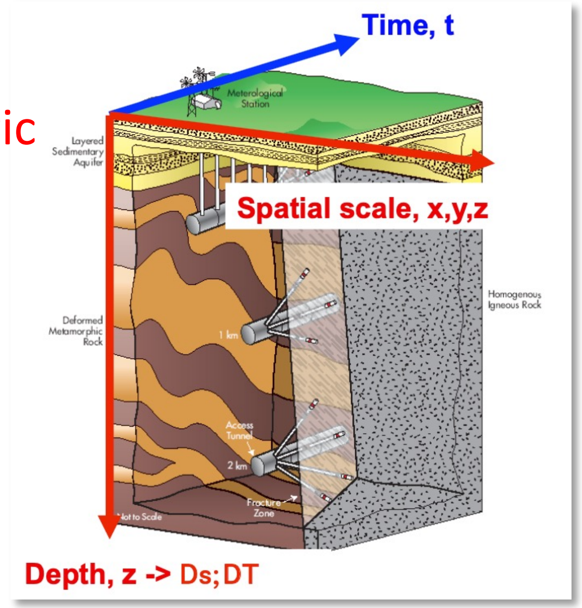
Large Depth – Elevated stress and temperature

Long Term Occupancy – Continuity

Low Background Noise – Seismically

Proximal Access – To processes/expts. At depth

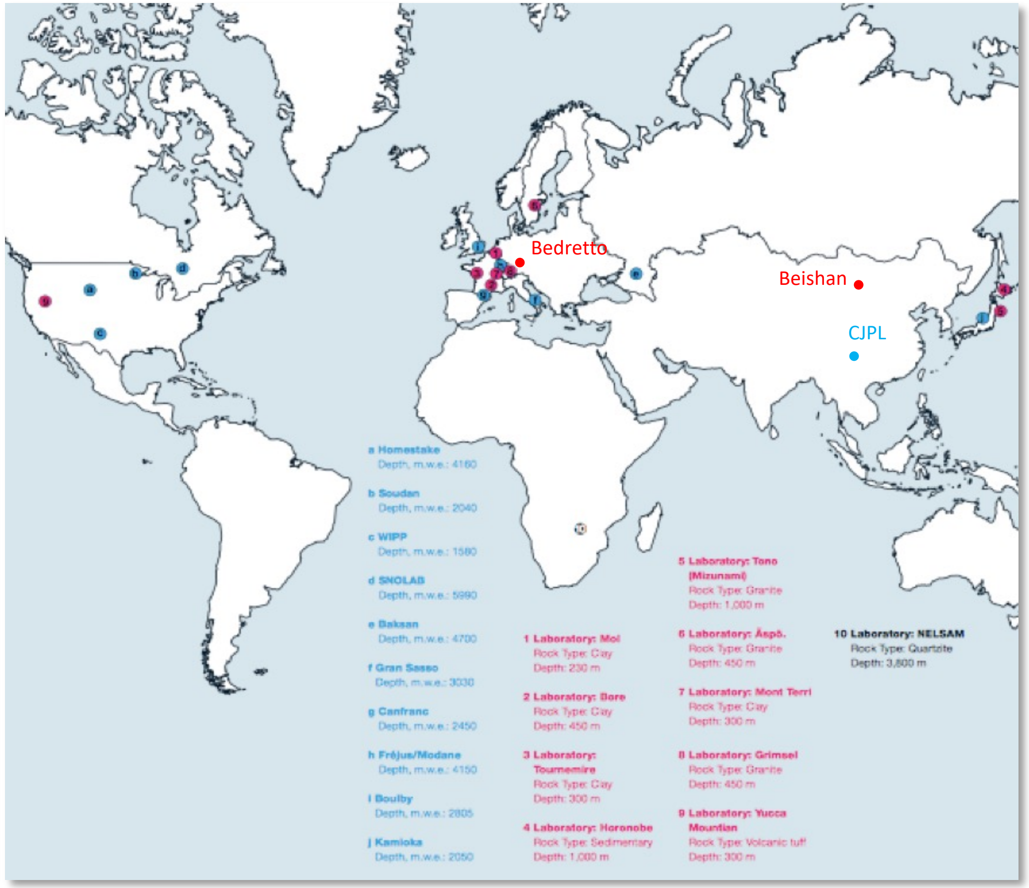
Active Experimentation – Ameliorates constraints of the (very specific) geologic environment



Con

Merely One Environment – Rock type/non-sedimentary

Many Competing Locations – Some with more-favorable/specific attributes



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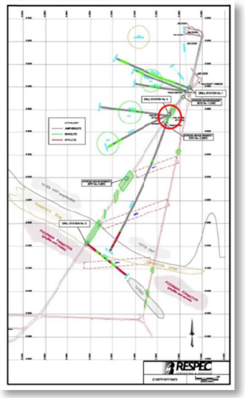
SURF Recent/Current Portfolio

kISMET: Permeability (k) and Induced Seismicity Management for Energy Technologies

A U.S. Department of Energy (DOE)-spon



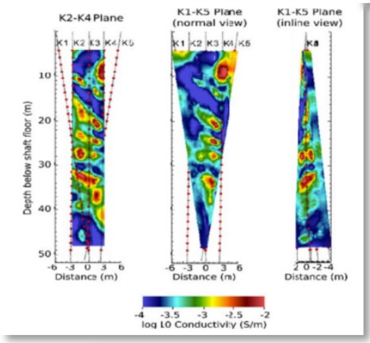

LBNL-1006444

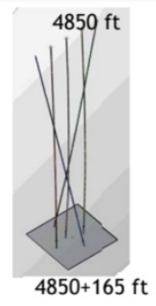
Intermediate-Scale Hydraulic Fracturing in a Deep Mine
kISMET Project Summary 2016

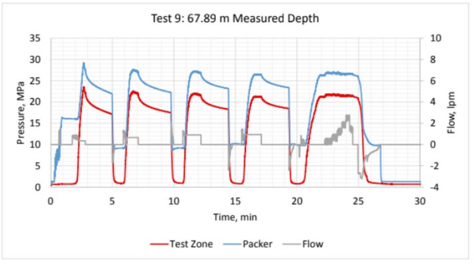
OLDENBURG, C.M.[1], DOBSON, P.F.[1], WU, Y.[1], COOK, P.J.[1], KNEAFSEY, T.J.[1], NAKAGAWA, S.[1], ULRICH, C.[1], SILER, D.L.[1 †], GUGLIELMI, Y.[1], AJO-FRANKLIN, J.[1], RUTQVIST, J.[1], DALEY, T.M.[1], BIRKHOLZER, J.T.[1], WANG, H.F.[2], LORD, N.E.[2], HAIMSON, B.C.[3], SONE, H.[3], VIGILANTE, P.[3], ROGGENTHEN, W.M.[4], DOE, T.W.[5], LEE, M.Y.[6], INGRAHAM, M.[6], HUANG, H.[7], MATTSON, E.D.[7], ZHOU, J.[7], JOHNSON, T.J.[8], ZOBACK, M.D.[9], MORRIS, J.P.[10], WHITE, J.A.[11], JOHNSON, P.A.[12], COBLENTZ, D.DD.[13], and HEISE, J.[14]

[1]Energy Geosciences Division, Lawrence Berkeley National Laboratory
[2]Department of Geoscience, University of Wisconsin-Madison
[3]Geological Engineering, University of Wisconsin
[4]Geology and Geological Engineering, South Dakota School of Mines & Technology
[5]FracMan Technology Group, Golder Associattes Inc.
[6]Sandia National Laboratories
[7]Idaho National Laboratory
[8]Energy and Environment Directorate, Pacific Northwest National Laboratory
[9]School of Earth, Energy, and Environmental Sciences, Stanford University
[10]Atmospheric, Earth, and Energy Division, Lawrence Livermore National Laboratory
[11]Lawrence Livermore National Laboratory
[12]EES-17, Geophysics Group, Los Alamos National Laboratory
[13]Earth and Environmental Sciences Division, Los Alamos National Laboratory
[14]Sanford Underground Research Facility

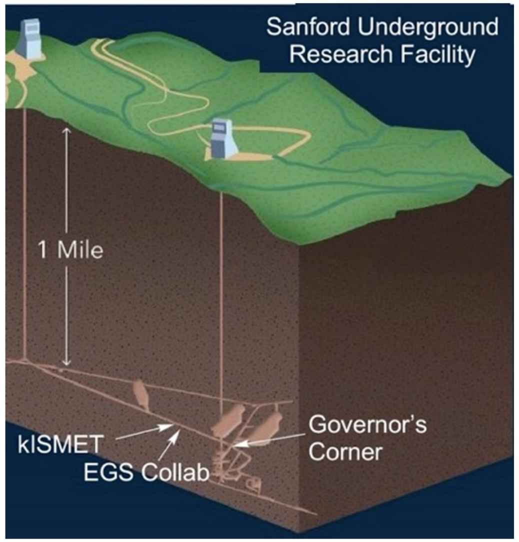
† Now at U.S. Geological Survey, Menlo Park, CA







DoE EGS Collab(oration) Project

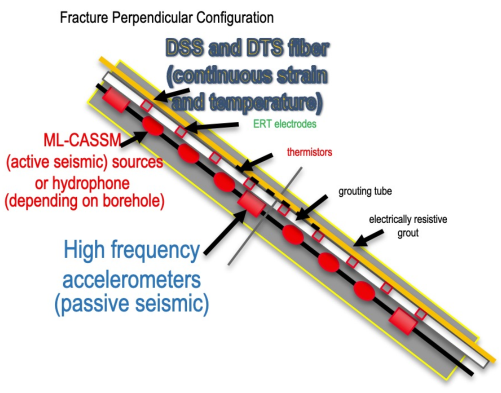


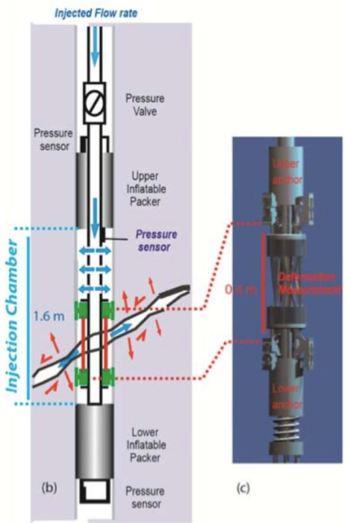
At Sanford Underground Research Facility (SURF-DUSEL) – 1500m

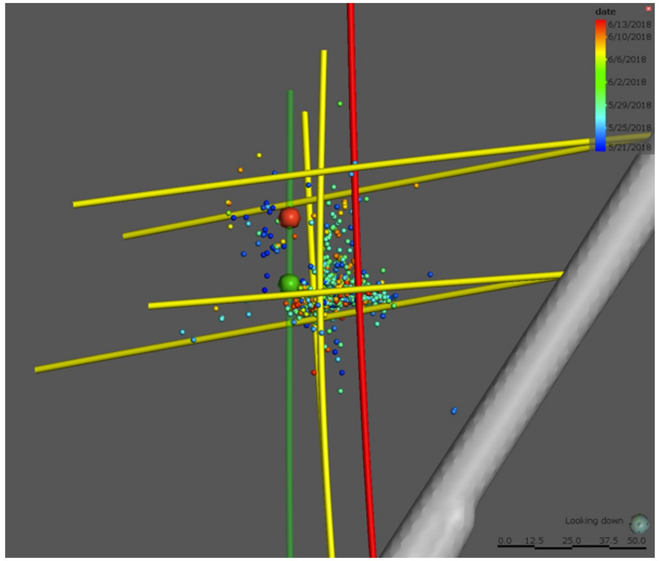
Experiment 1, intended to investigate hydraulic fracturing*, in situ

Experiment 2 designed to investigate shear stimulation*.

Experiment 3 will investigate changes in fracturing strategies – TBD.





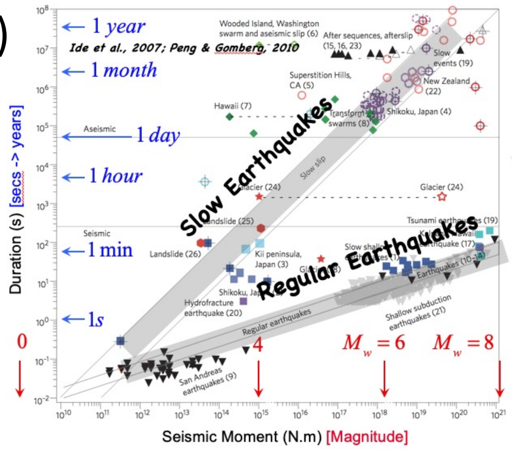


Courtesy: Tim Kneafsey (LBNL), Tim Johnson (PNNL), Hunter Knox (SNL), Jonathan Ajo-Franklin (LBNL), Paul Cook (LBNL), Yves Guglielmi (LBNL), Martin Schoenball (LBNL), Hari Neupane (INL) & EGS Collab.

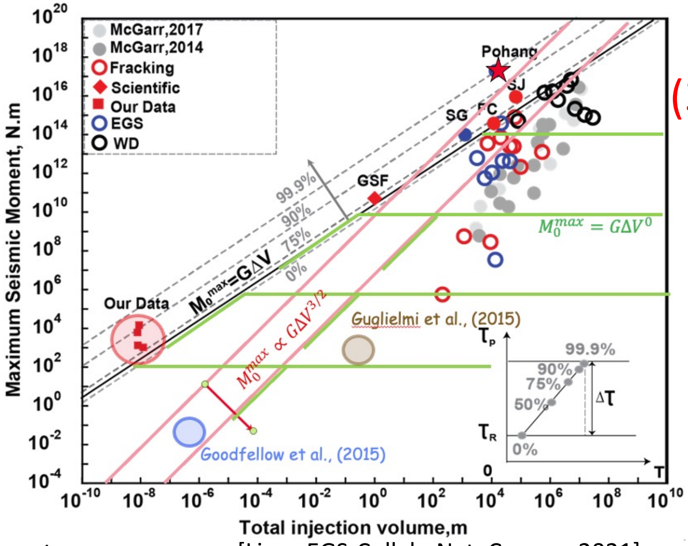
What big science questions will need to be addressed?

- What is an earthquake? [NSF Decadal Review, 2020 + Lapusta et al., 2019]
  - Nucleation, rupture and termination
  - Precursory signatures and AI/ML
  - Spectrum of slip modes – slow to fast (1)
  - Magnitude invariance of stress drop (2)
  - Scaling controls on M_{max} –vs– delta V (3)
  - Role of in situ stresses
  - Slow –vs– fast EQ-slip influence on permeability
  - Controls on permeability through the EQ cycle (4)
  - Relations among rupture/healing and breaching/sealing
- What are the interactions among complex subsurface processes?
  - Adaptive control of fluid transport/permeability (SubTER & Collab)
  - Stimulation methods (sub- and super-sigma_3) (Collab)
  - Proppant transport – roles of tortuosity
  - Novel methods of stimulation – energetic and soft
- Can we view complex underground processes in action?
  - Sensing for state and constitutive behavior
  - Distributed sensing methods (fiber) + others
  - Testbed data sets for AI/ML

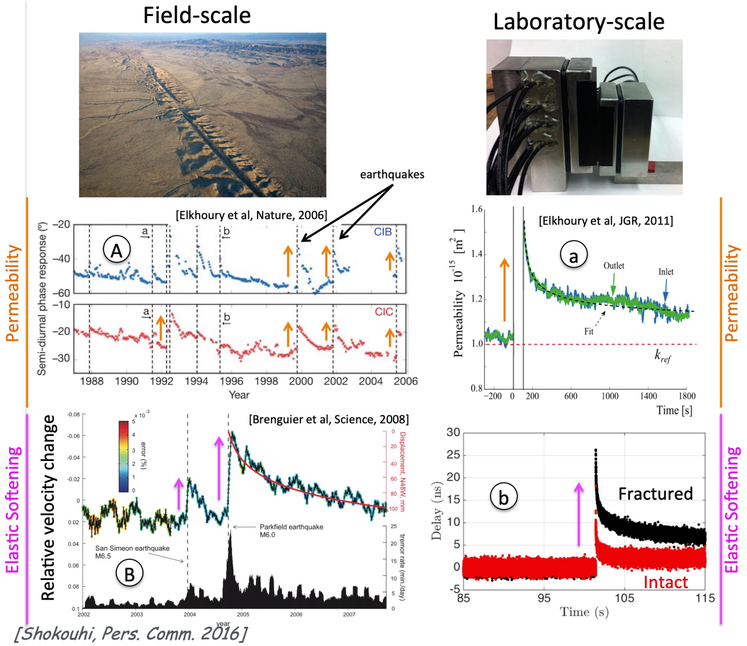
(1)



(3)



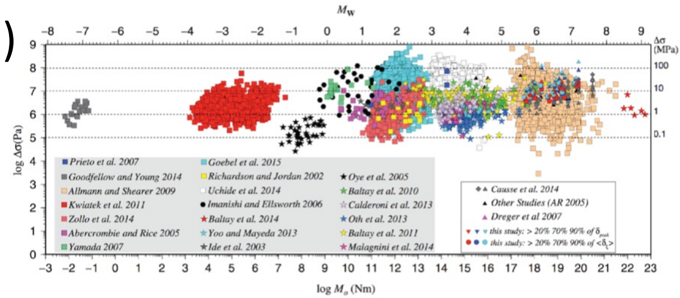
[Li, ..., EGS-Collab, Nat. Comm., 2021]



[Shokouhi, Pers. Comm. 2016]

(4)

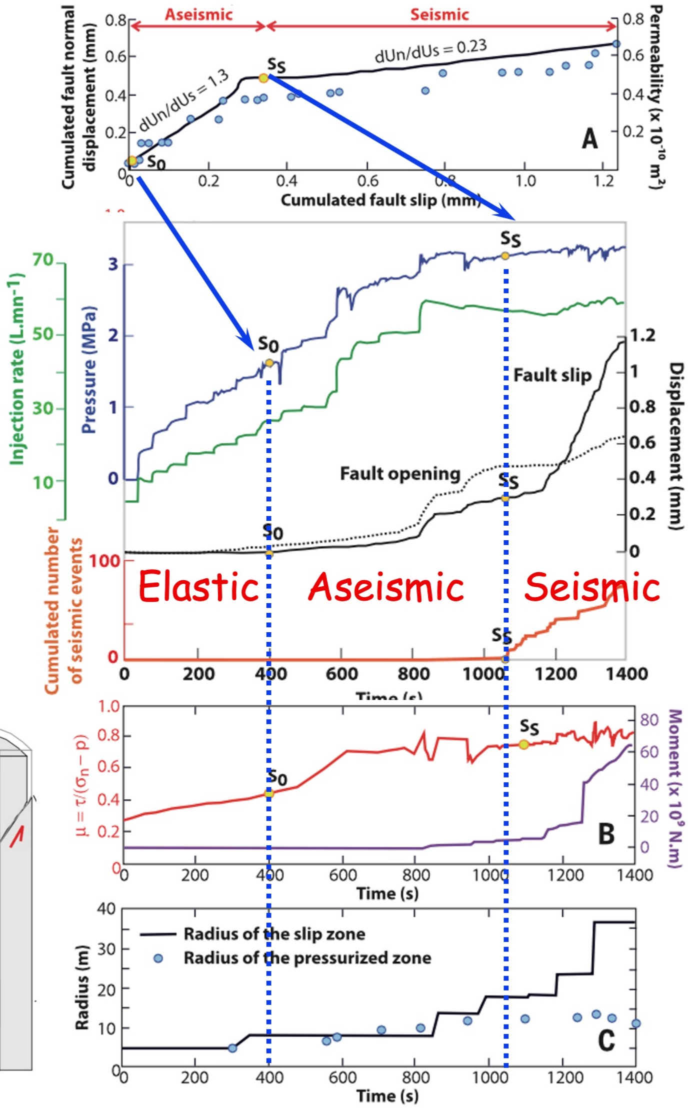
(2)



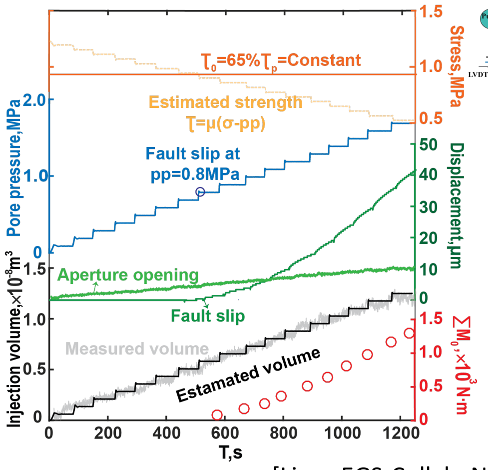
[from, Lapusta et al., Community Rept. to NSF, 2019,]

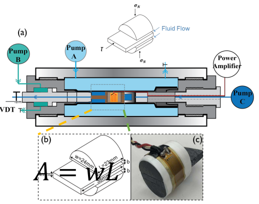
What are the approaches to addressing these questions?

URL Scale



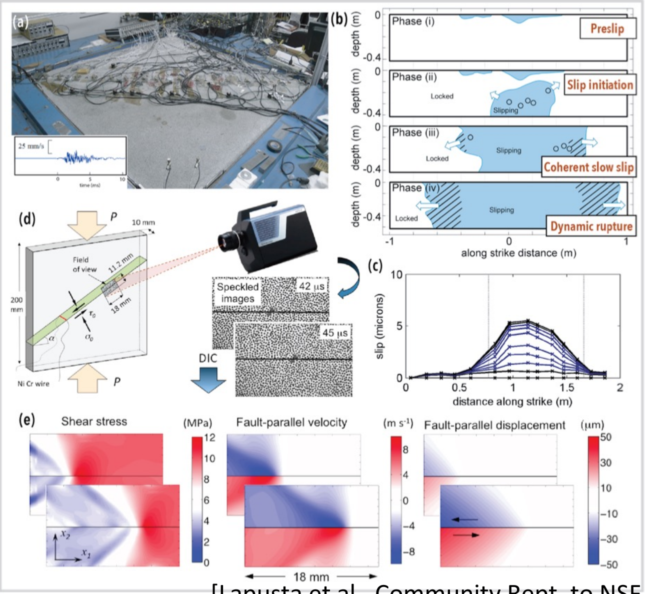
Laboratory Scale





[Li, ..., EGS-Collab, Nat. Comm., 2021]

Across-the-scales



[Lapusta et al., Community Rept. to NSF, 2019,]

Scale Dependence – the need for URLs and constrained experimentation at meso scale.

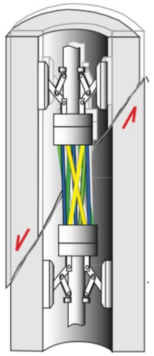
$$K_c = \frac{(\sigma_n - p)(a-b)}{D_c} > \frac{G}{l} = K$$

Roles of:

Pressurization $(\sigma_n' \rightarrow 0)$

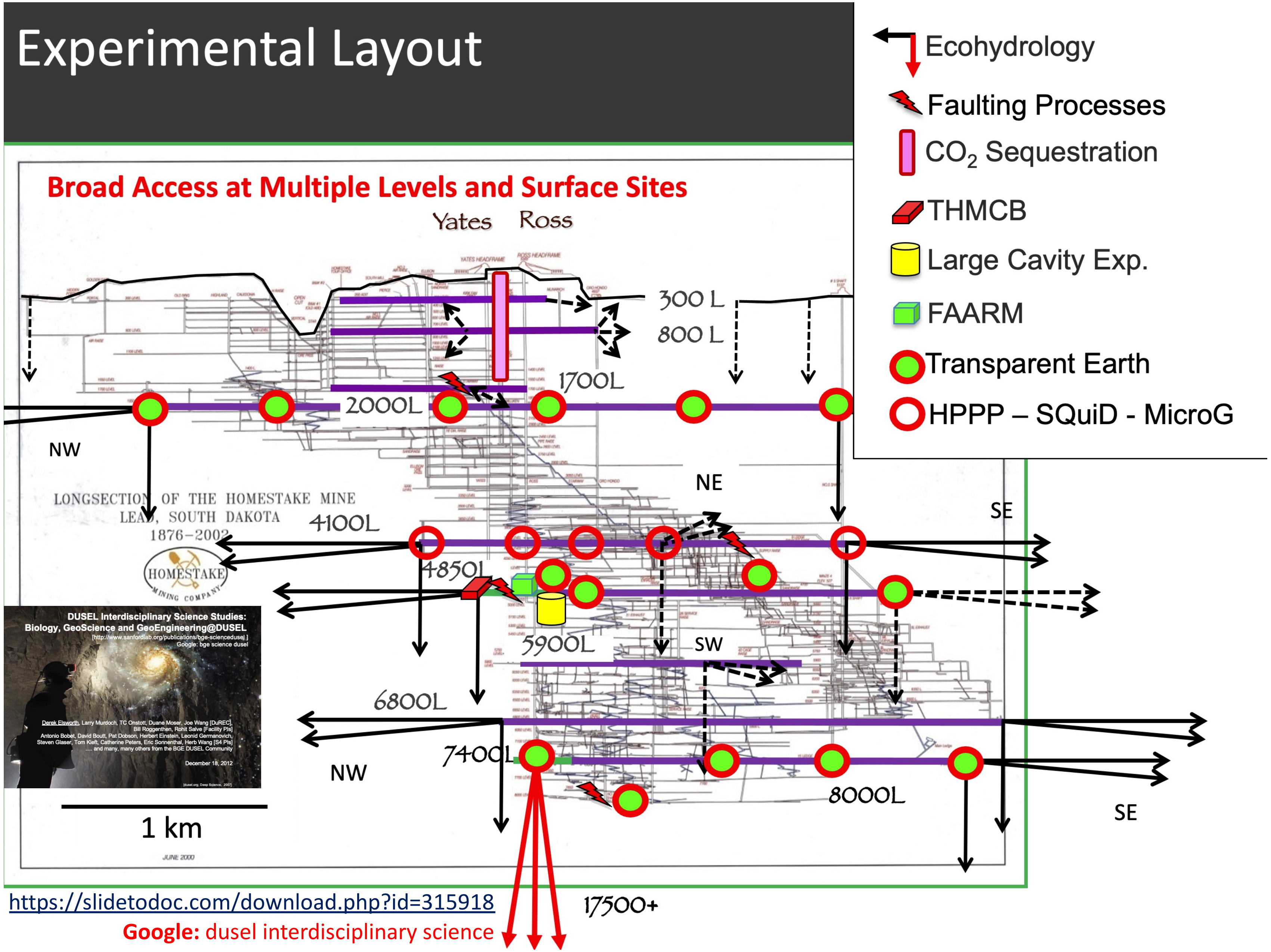
Deformation ahead of the fluid front

Mineralogical controls



[Guglielmi et al., Science, 2015]

Facility Needs? – c. 2010 View of DUSEL/SURF



https://slidetodoc.com/download.php?id=315918

Google: dusel interdisciplinary science

2020-2040 Needs?

Distant from physics experiments?

Range of depths: stresses/temp

Access to geological structures

.. faults? .. others

Vertical/horizontal section access

.. for non-active experiments

Opportunity alcoves and adits

.. use mobilized equip.

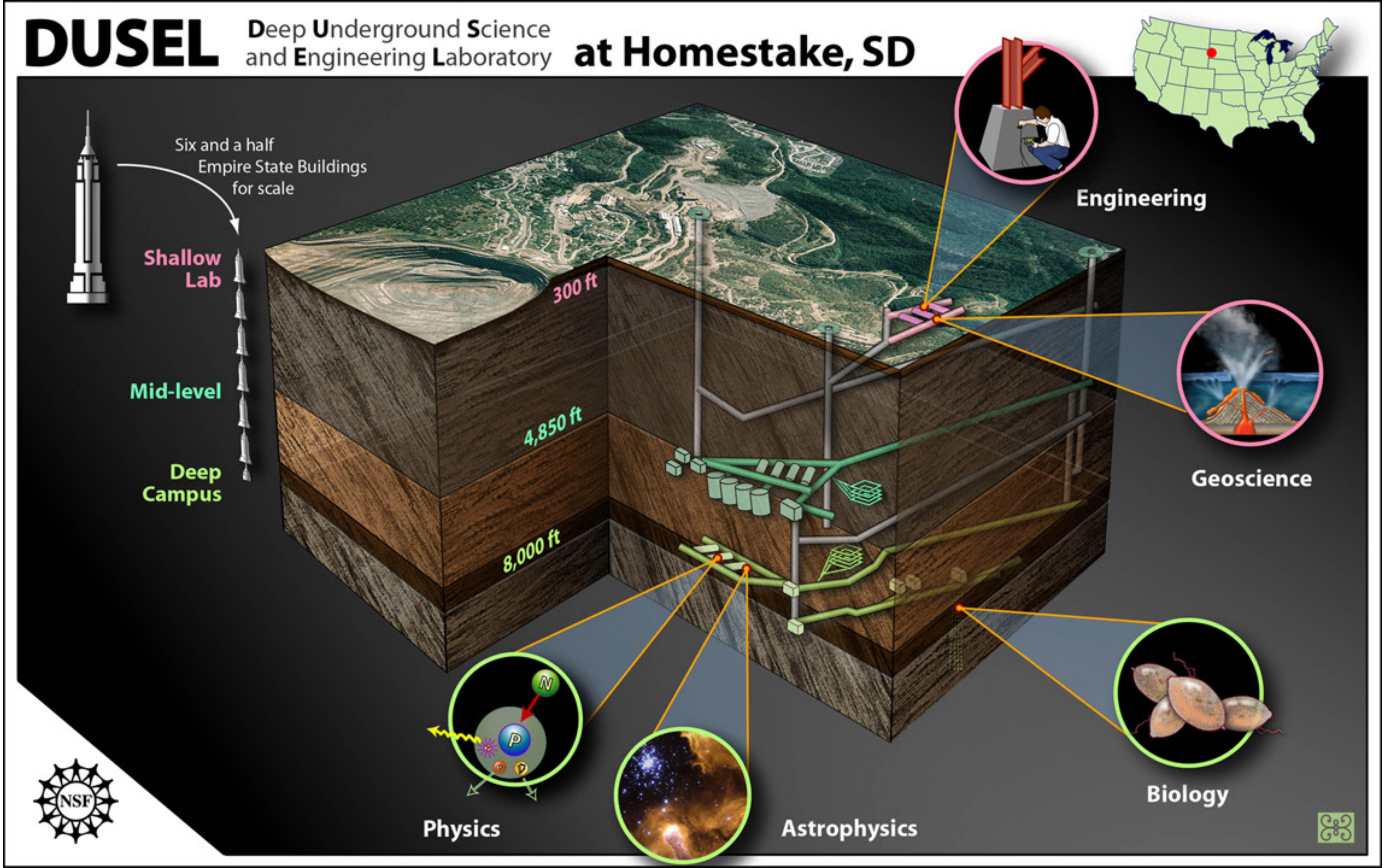
.. clearance for drill rigs/tools

Normal utilities/supplies

.. water, power, internet…

+ Funding to do the science …

Assistance with Community Involvement and Outreach Efforts?


DUSEL
Deep Underground Science and Engineering Laboratory
at Homestake, SD
Six and a half Empire State Buildings for scale
Shallow Lab
Mid-level
Deep Campus
300 ft
4,850 ft
8,000 ft
Engineering
Geoscience
Biology
Physics
Astrophysics
N
P
NSF