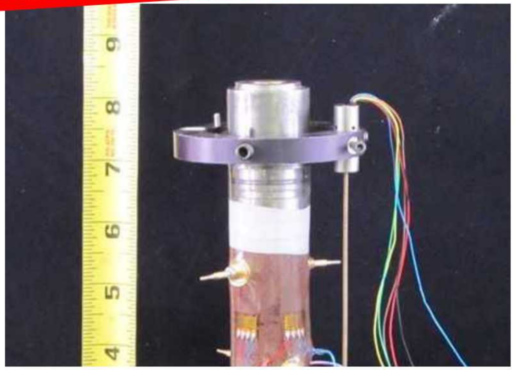
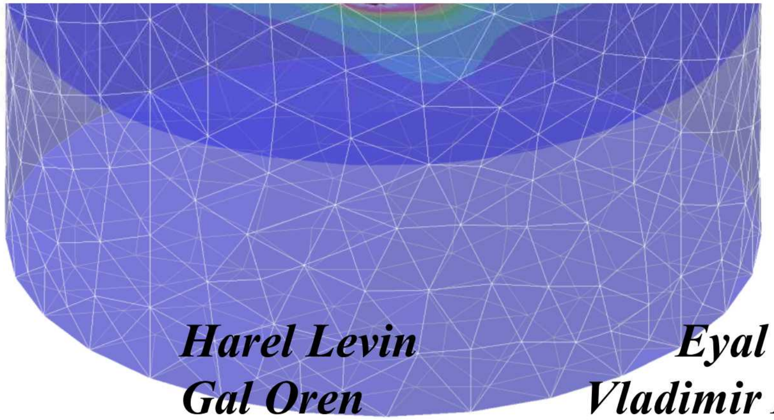
SAND2019-13618C

~~Damage accumulation and wellbore stability~~



Thermal, Hydrological, and Mechanical (THM) Modelling



Steve Bauer
Charles Choens

Michael Homel
Antoun Tarabay

Harel Levin
Gal Oren

Eyal Shalev
Vladimir Lyakhovsky

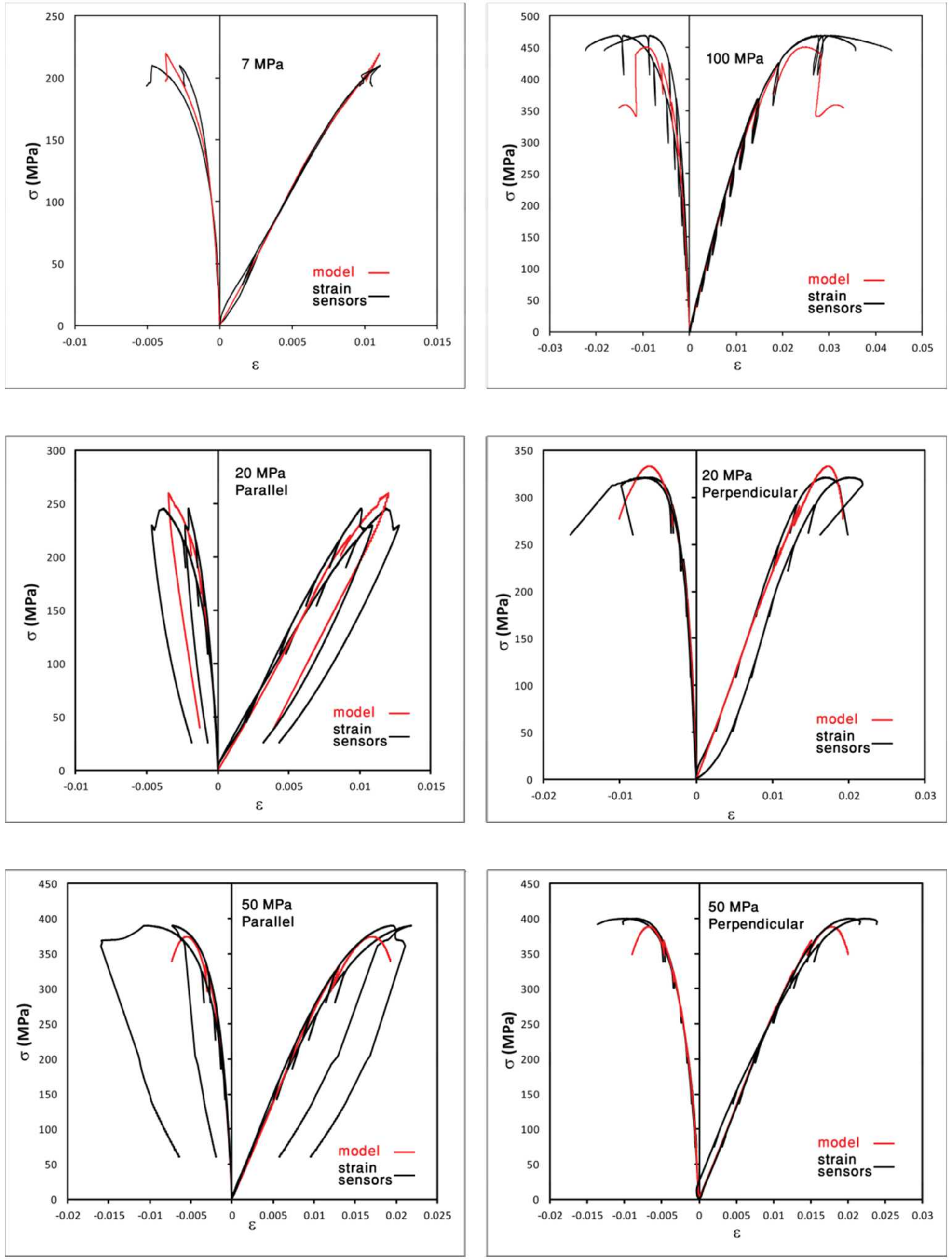
Sandia National Laboratories

Lawrence Livermore National Laboratory

Sandia National Laboratories is a multimission laboratory managed and operated by National Technology and Engineering Solutions of Sandia, LLC., a wholly owned subsidiary of Honeywell International, Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA-0003525.

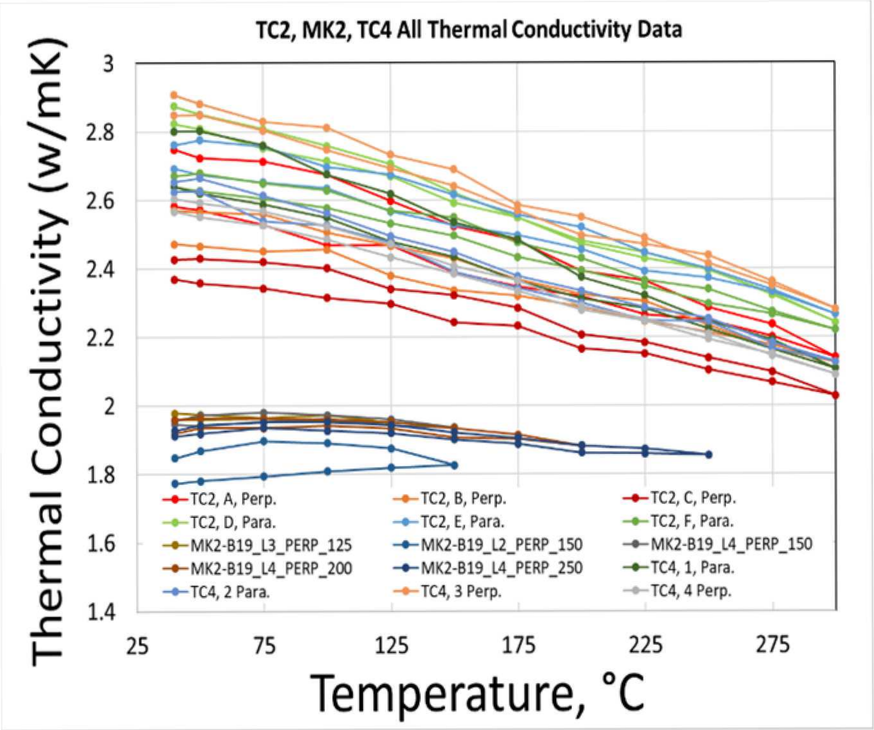
Previously…

Experimental data and poro-elastic damage model

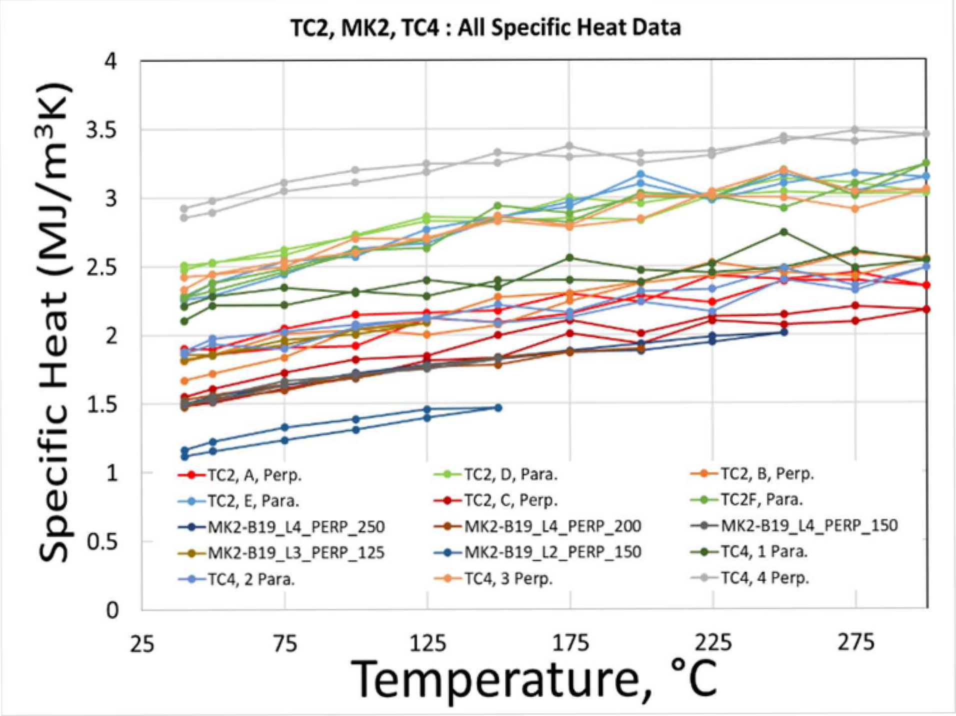


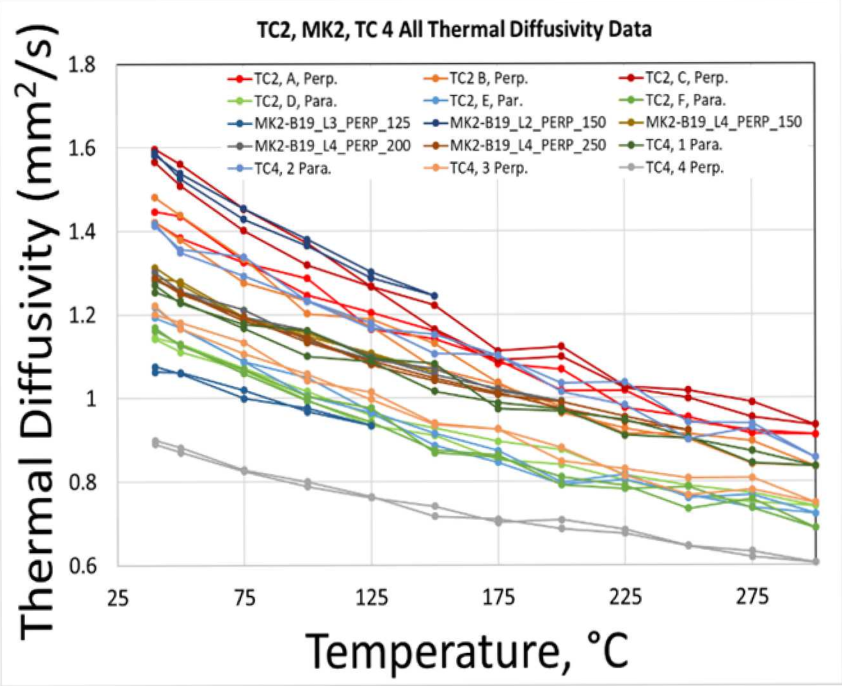
Test	pressure	Orient	Lambda	G	ksi_0	Cd
2933	100	Perp	6000	12000	-0.4	50
8433	20	Paral	6000	10500	-0.4	50
8434	20	Perp	6000	10000	-0.4	30
8435	50	Paral	6000	12000	-0.4	50
8436	50	Perp	6000	11500	-0.4	25
8437	7	Perp	6000	10000	-0.4	12

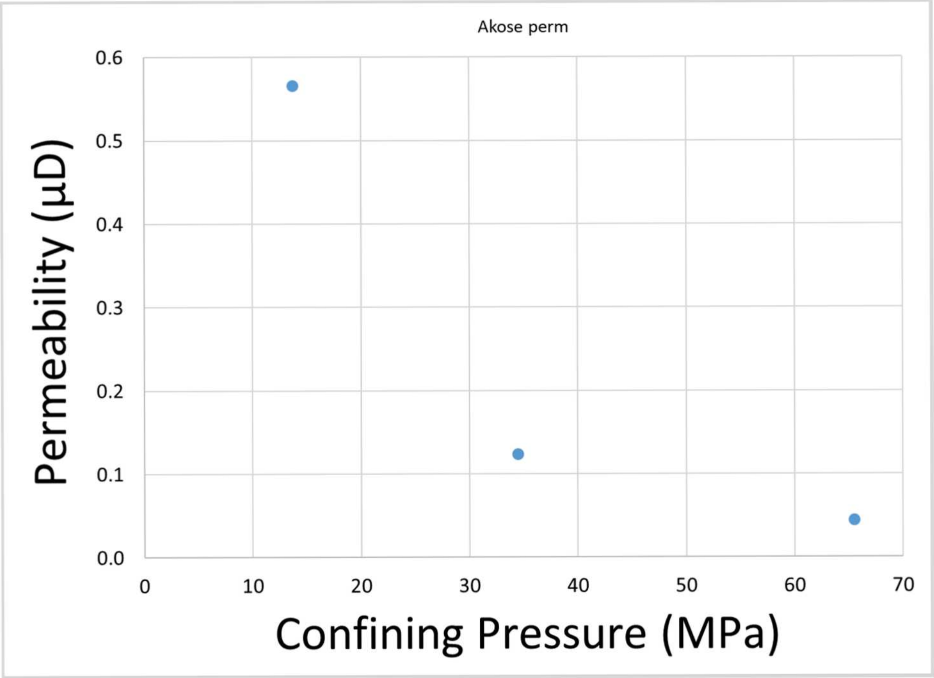
~15 triaxial tests

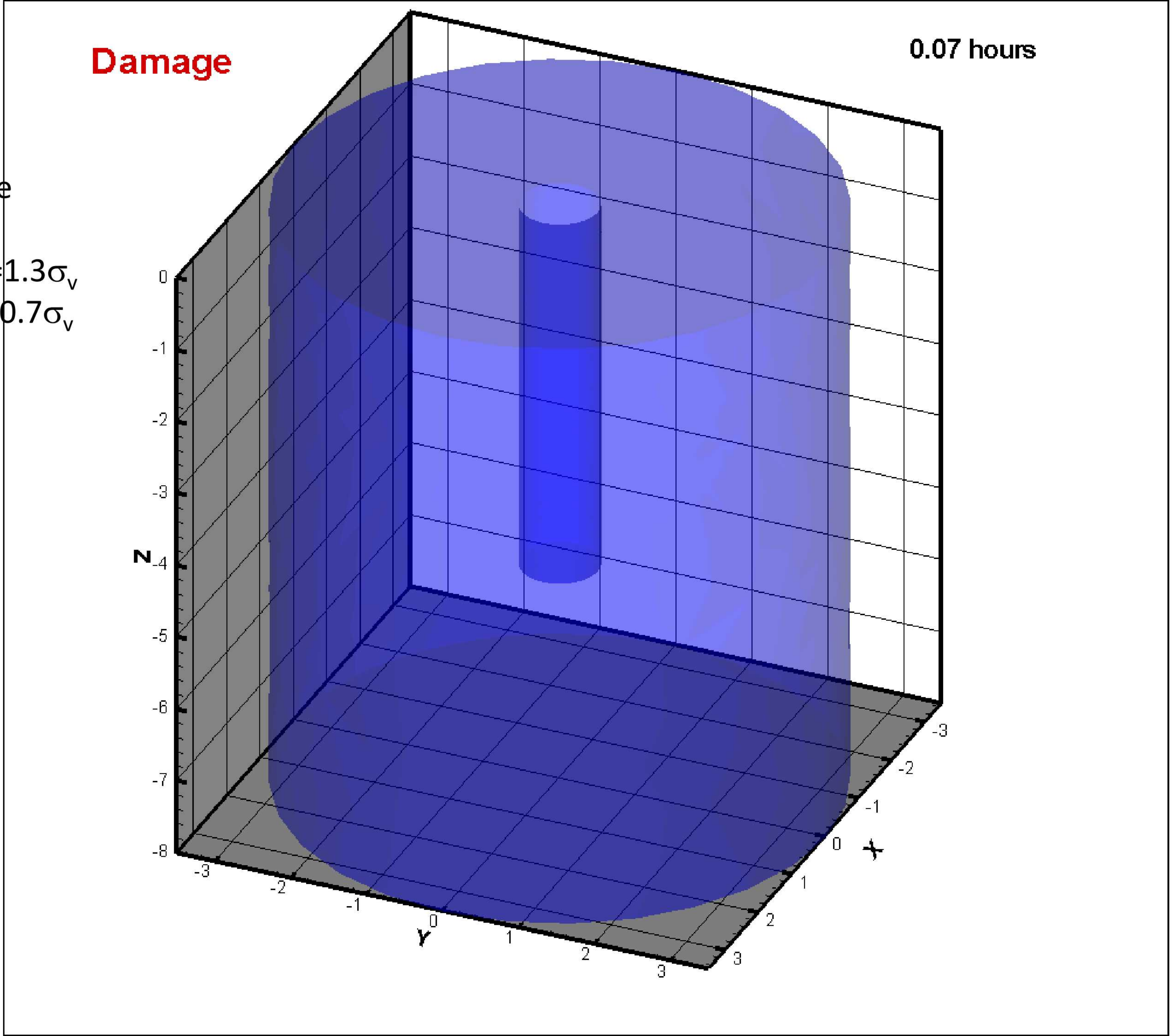


Thermal,
Hydrologic properties
~200 measurements







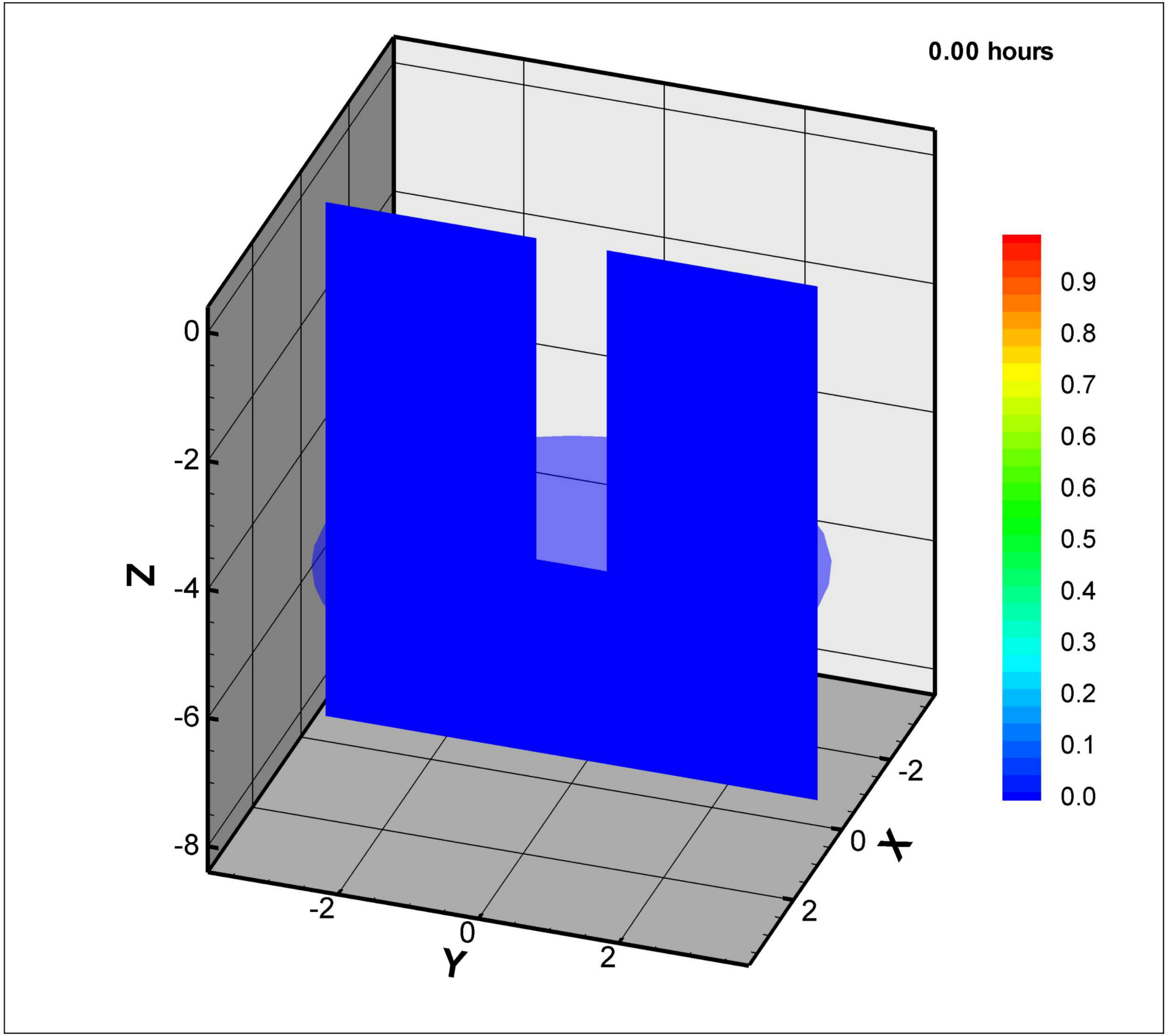


Granite
5 KM
$\sigma_{Hmax}=1.3\sigma_v$
$\sigma_{Hmin}=0.7\sigma_v$

Zenifim 5 KM

$\sigma_{Hmax}=1.3\sigma_v$

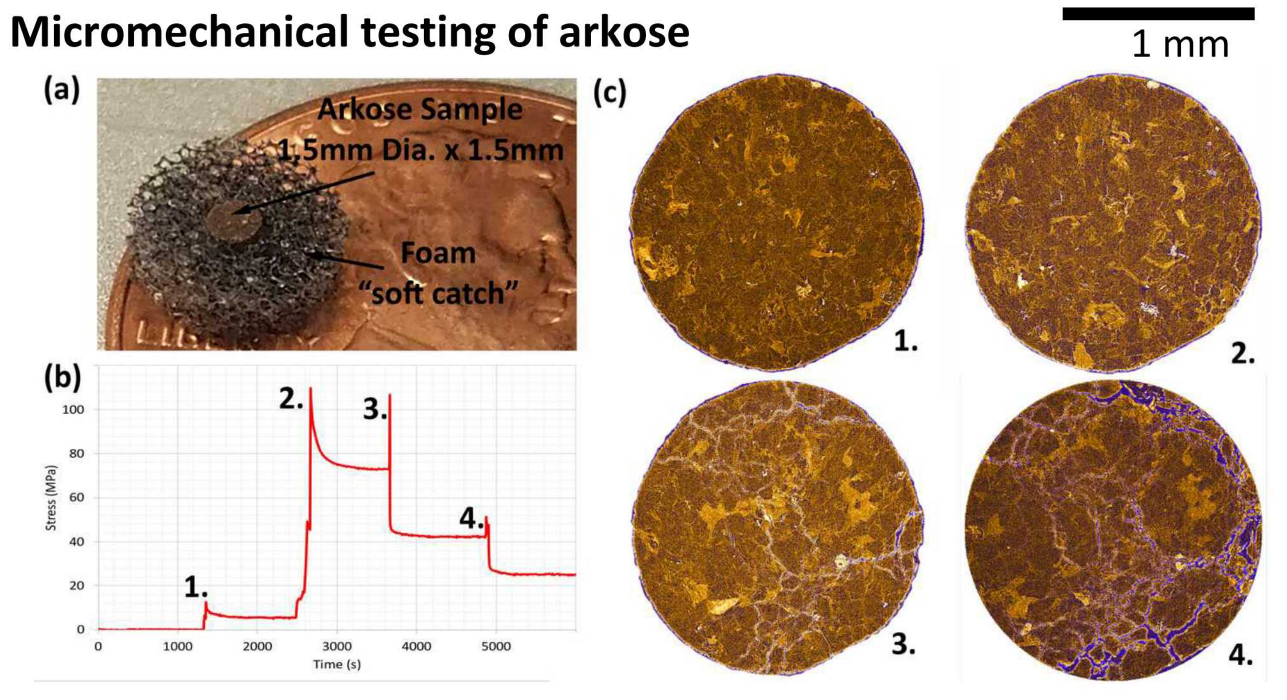
$\sigma_{Hmin}=0.7\sigma_v$



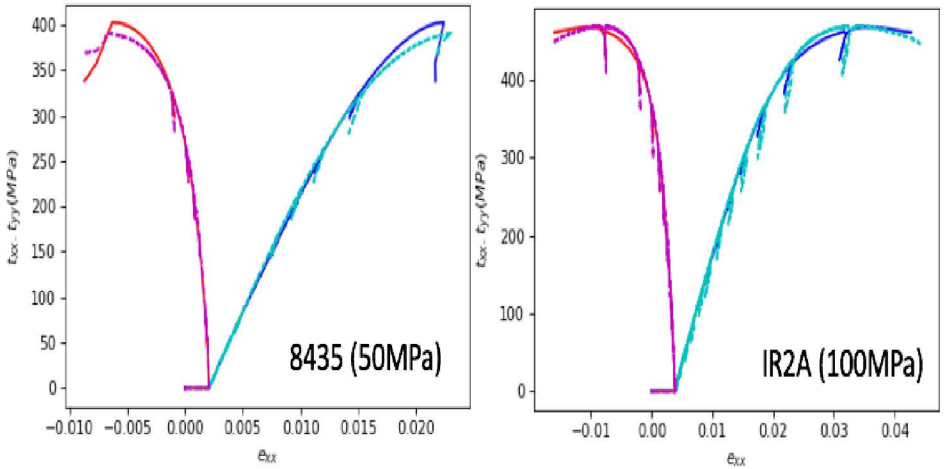
Simulating Damage Induced by Excavation/Heat Release (LLNL Deep borehole damage and breakout modeling): Improved understanding of Zenifim (arkose) material response for more predictive simulations

- Micromechanical testing and analysis of material response in triaxial compression tests has identified bulking (shear-enhanced compaction) as the primary dissipation mechanism in the arkose material.
- Numerical optimization methods were used to obtain parametrizations for our GEODYN material models that accurately capture the poro-elastic, yielding, and post-failure response in the arkose material

Micromechanical testing of arkose

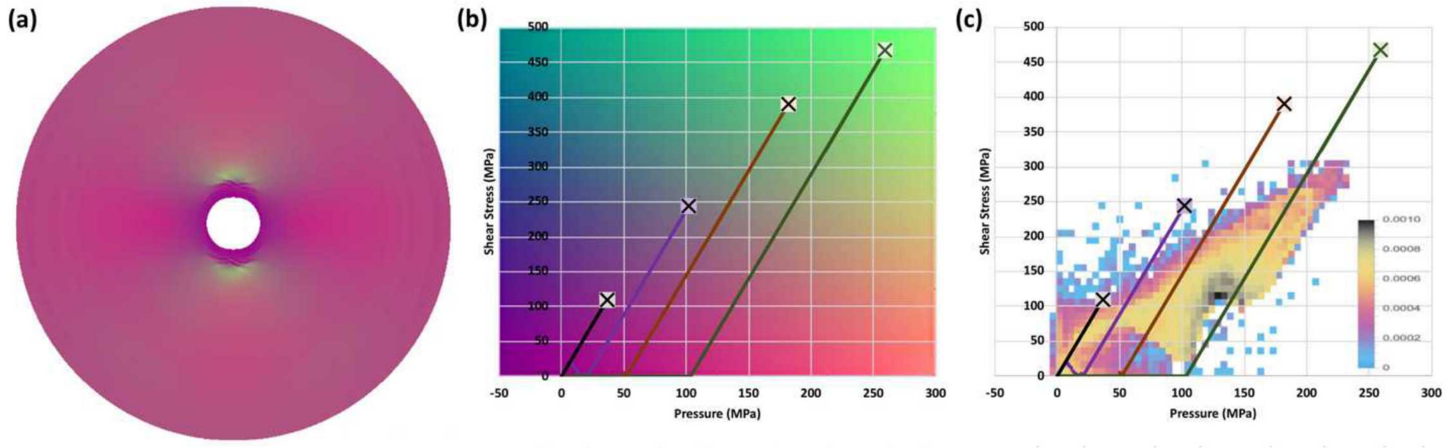


Material model validation:



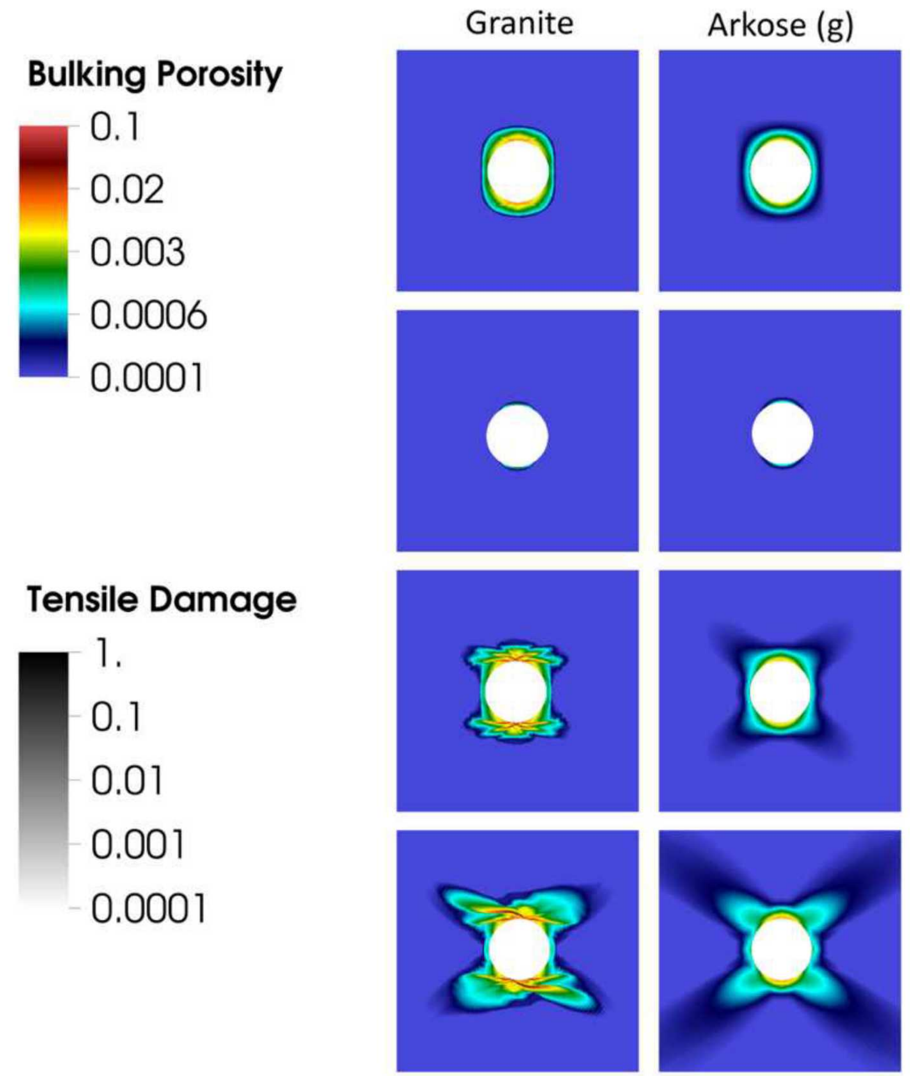
Borehole breakout simulations used to assess effects of uncertainty in material properties.

- Simulations of damage in wellbore excavation used to study effect on stability of uncertainty in the material model properties that are unconstrained by available experimental data.
- Uncertainties remain, but analysis predicts the Zenefim (arkose) formation to be more stable during excavation than the crystalline (granite) basement, despite the nominally higher strength in the granite material.



Stress states in breakout and in experimental data

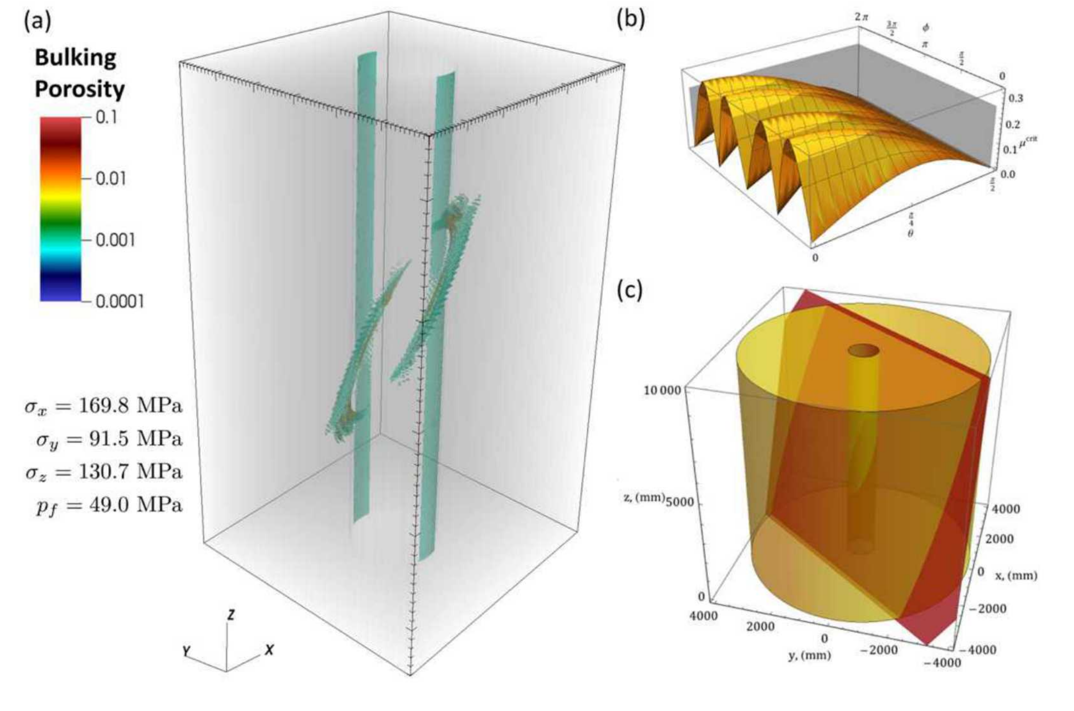
Borehole breakout simulations:

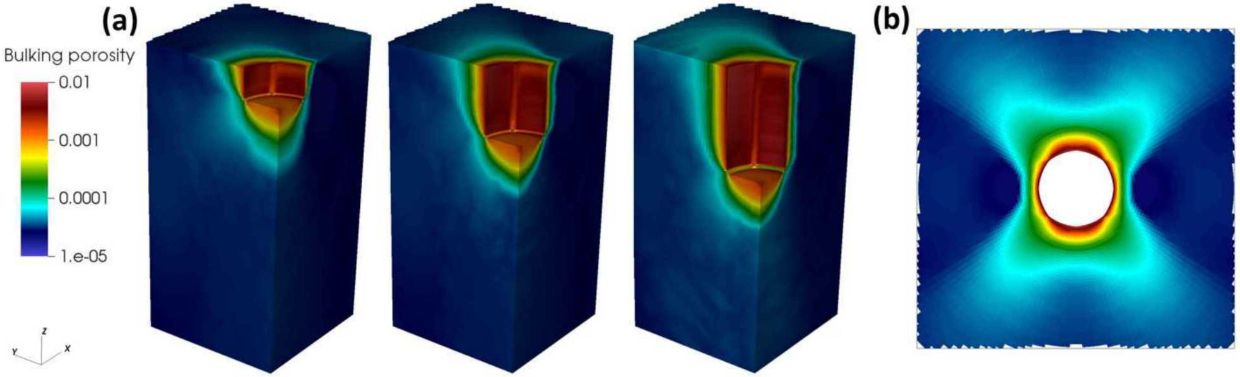


Analysis of complex damage mechanisms in borehole excavation.

- Analysis of fracture-borehole interactions showed instability can arise even when the borehole and fracture are independently stable under a given stress state.
- 3-D simulations of an evolving wellbore geometry showed a history effect during excavation that is not captured by static simulations of a 2-D or 3-D borehole.

3-D Well-bore fracture interactions





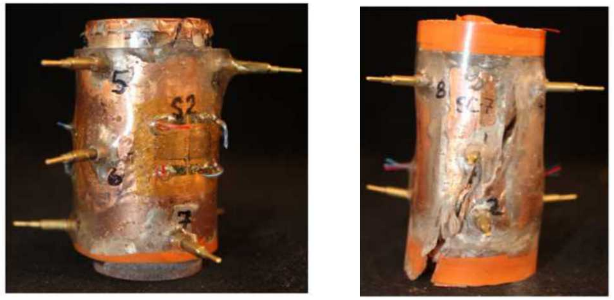
History effect of evolving wellbore geometry on damage

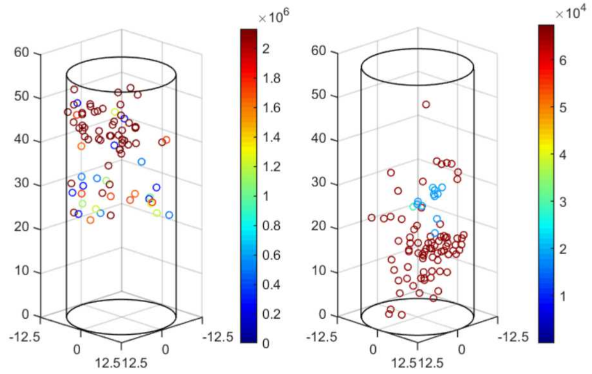
Generally, we find that common simplifying assumptions in wellbore stability analysis are non-conservative and more sophisticated methods should be used.

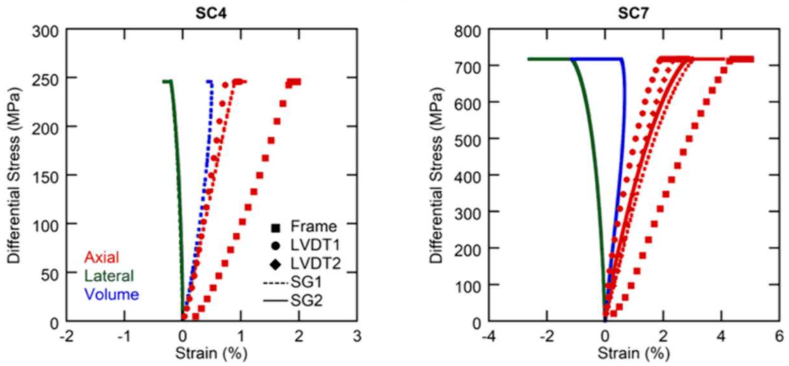
Time Dependent Behavior in Zenafim fm.

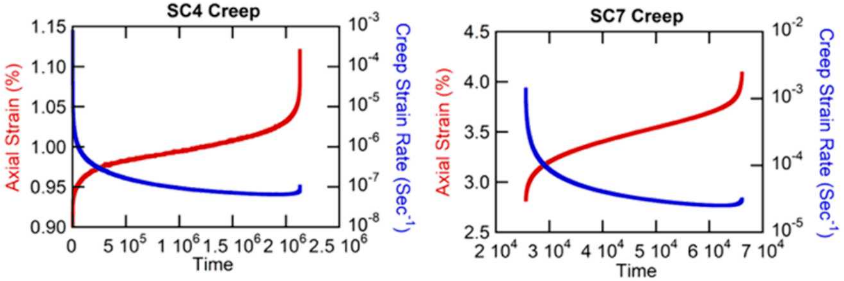
- 2 Successful creep tests
  - Captured 3 phases of creep
- Time to failure depends on conf pressure, applied load
  - SC-4: 2129659 sec
  - SC-7: 40539 sec
- Acoustic Emissions
  - Majority of AEs near failure
  - Located events around fracture growth in samples
- Working with Eyal to model localization, time dependence
- Time dependent behavior important for predicting Mt. Scopus behavior
  - Chalks, oil shales show time dependent behavior
  - In situ, engineered conditions could have temperature, partial saturation to increase creep

SC-4 Pc=6.9 MPa SC-7 Pc=200 MPa



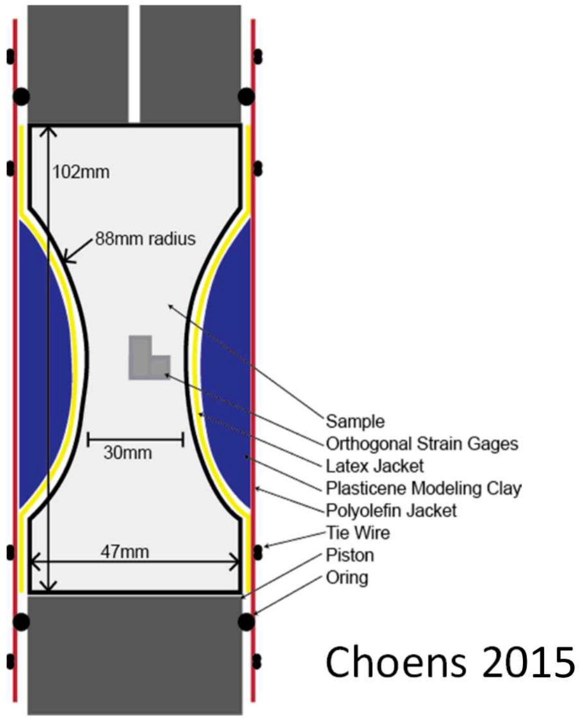




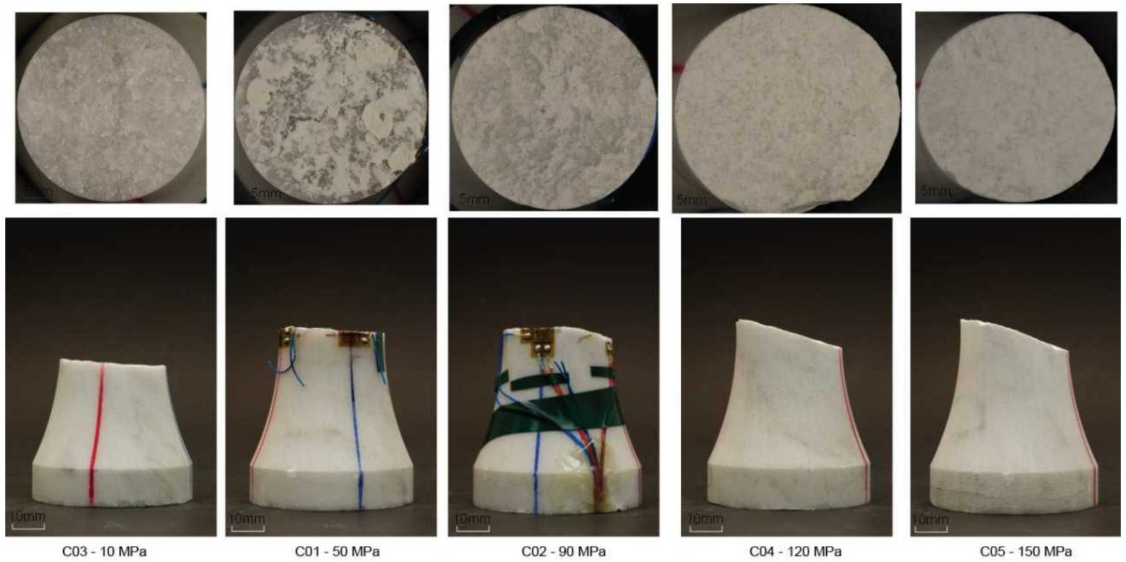


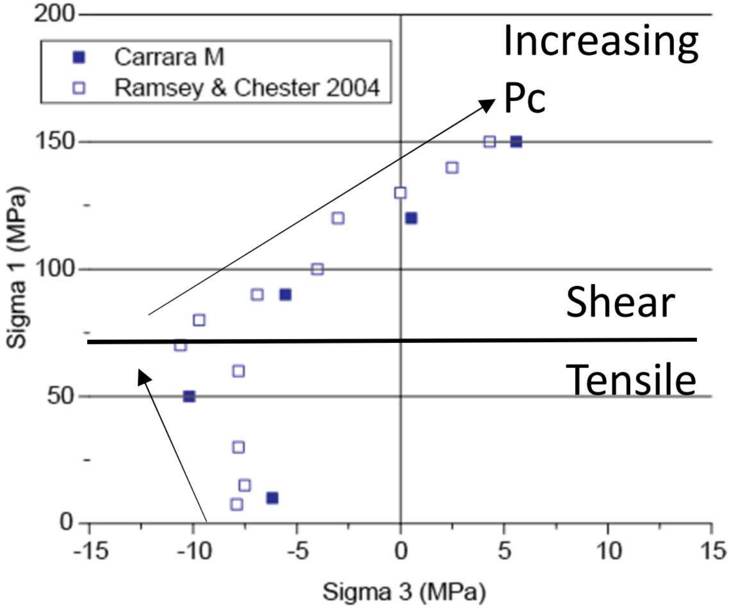
Low Mean Stress Failure

- Stress state likely present around wellbores
- Failure at low mean stresses not well described by conventional criterion
  - Transition between extensional and shear fracture
  - Characteristic strengths, fracture angle, and morphologies in stress state
- Sandia has developed test method and data analysis for low mean stress conditions

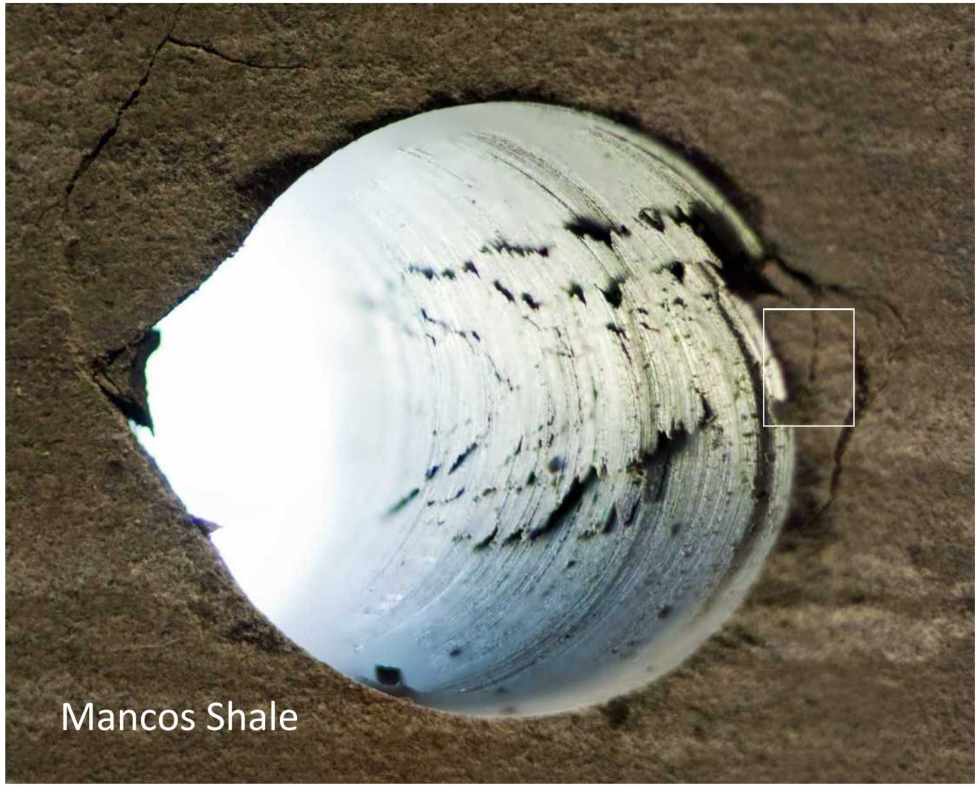


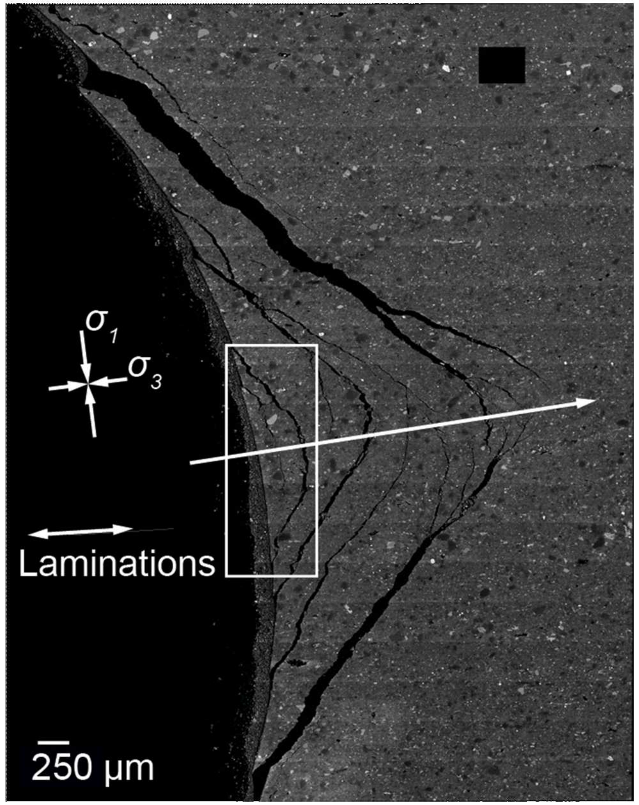
Choens 2015

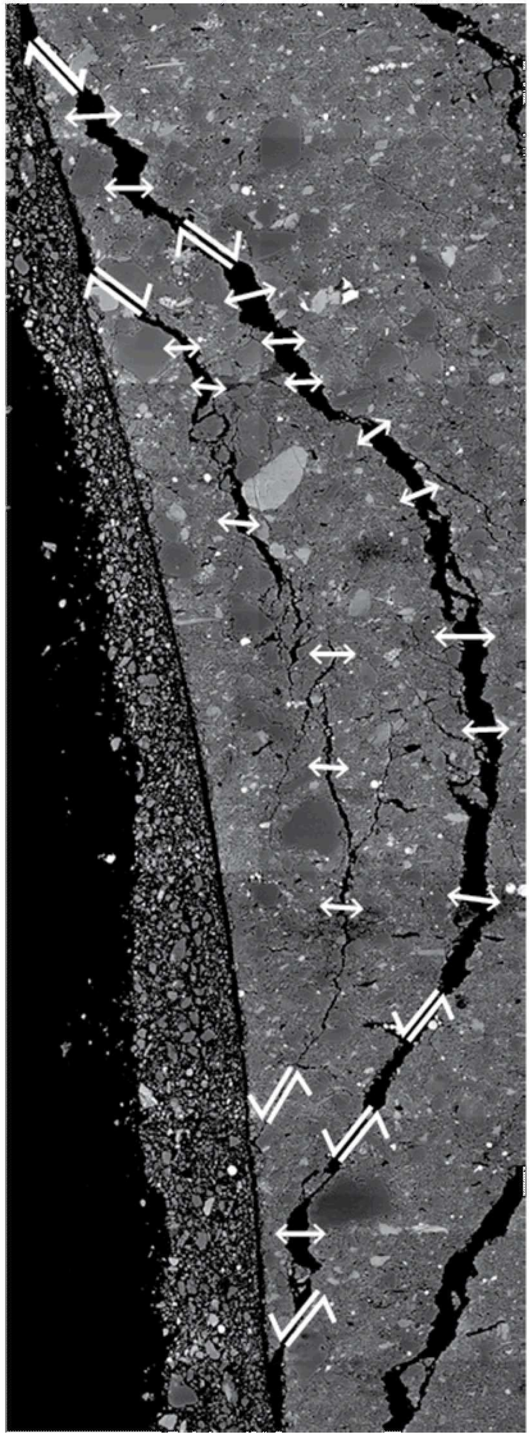




Lab studies of borehole breakouts







- Investigate bedding effects upon borehole breakout
- 3 sample orientations: parallel, perpendicular, and 45° to bedding
- Clear variations in borehole strength, mechanism

- Completing initiated work on Zenafim fm using model to predict stability
- Good approach for Mt. Scopus formation
- Investigate behavior with time, temperature

Thermal,Hydrological, and Mechanical (THM) Modelling

- The safety assessment of a repository for nuclear waste requires the demonstration of the integrity of the geological and geotechnical barriers.
- Thermal, hydraulic, and mechanical processes need to be considered
- These processes interact and influence each other in a complex manner.

The thermal, mechanical and hydrologic properties of chalk are complex and are stress, temperature, time and chemically dependent

In Situ Conditions + Engineered Conditions

- Consider Figure g29, depth range 170-320m, 558-1050ft
- In situ Stress: $\sigma_v = \rho g h$, 3.9-7.2MPa 560-1050psi

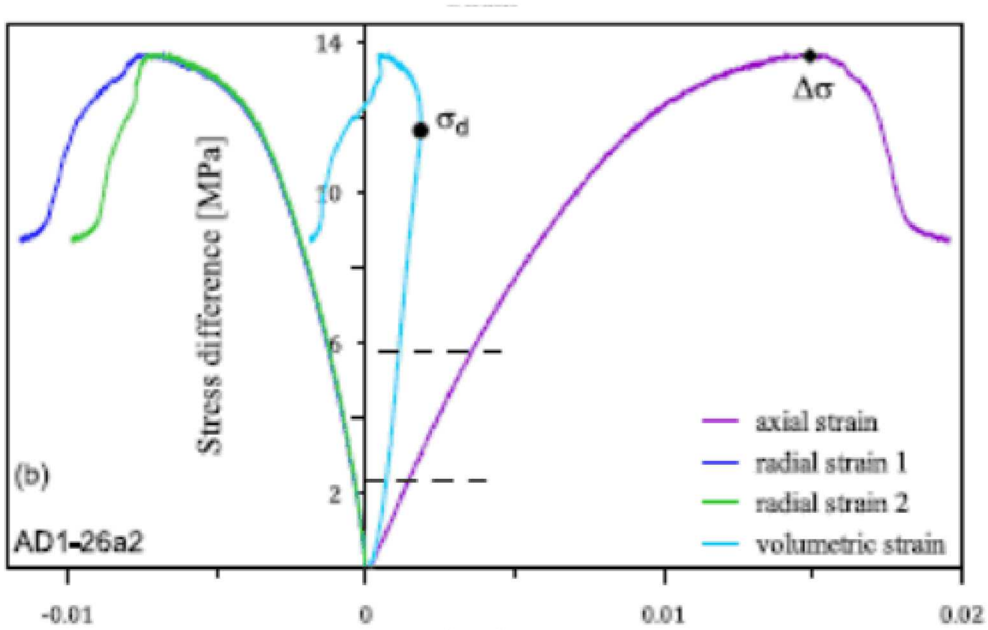
  $\sigma_{h,H} = f(\sigma_v)$ 1/3 to 1 x σ_v?
- In situ temperature= Ambient?

- Borehole induced stresses TBD
- Thermal loading induced stresses TBD
- In situ hydrology modifications TBD

Ghareb Chalk

Properties from the Shefela 80-100 km north of NRCN:

Permeability – 0.001 – 1 mD
Porosity 37%
Poisson's ratio – 0.37
Young's modulus – 7.8 GPa



Bisnovat et al., 2015

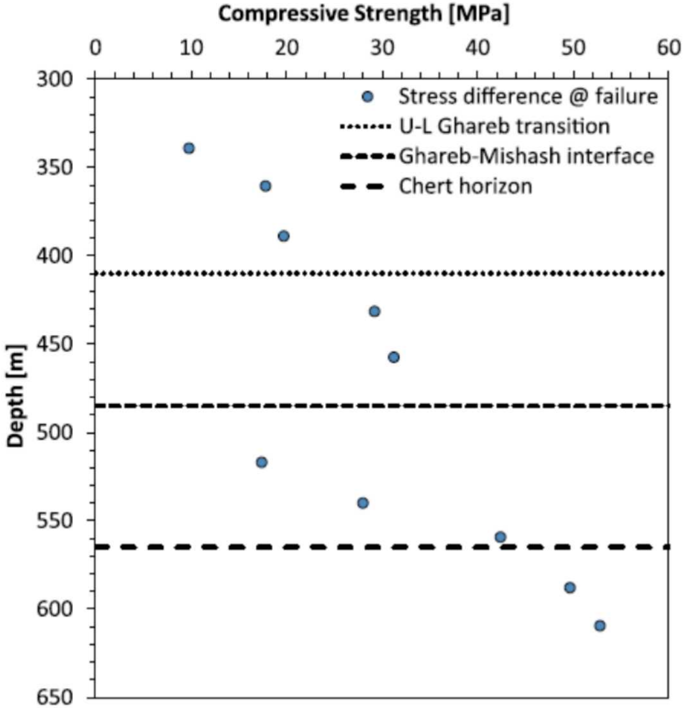
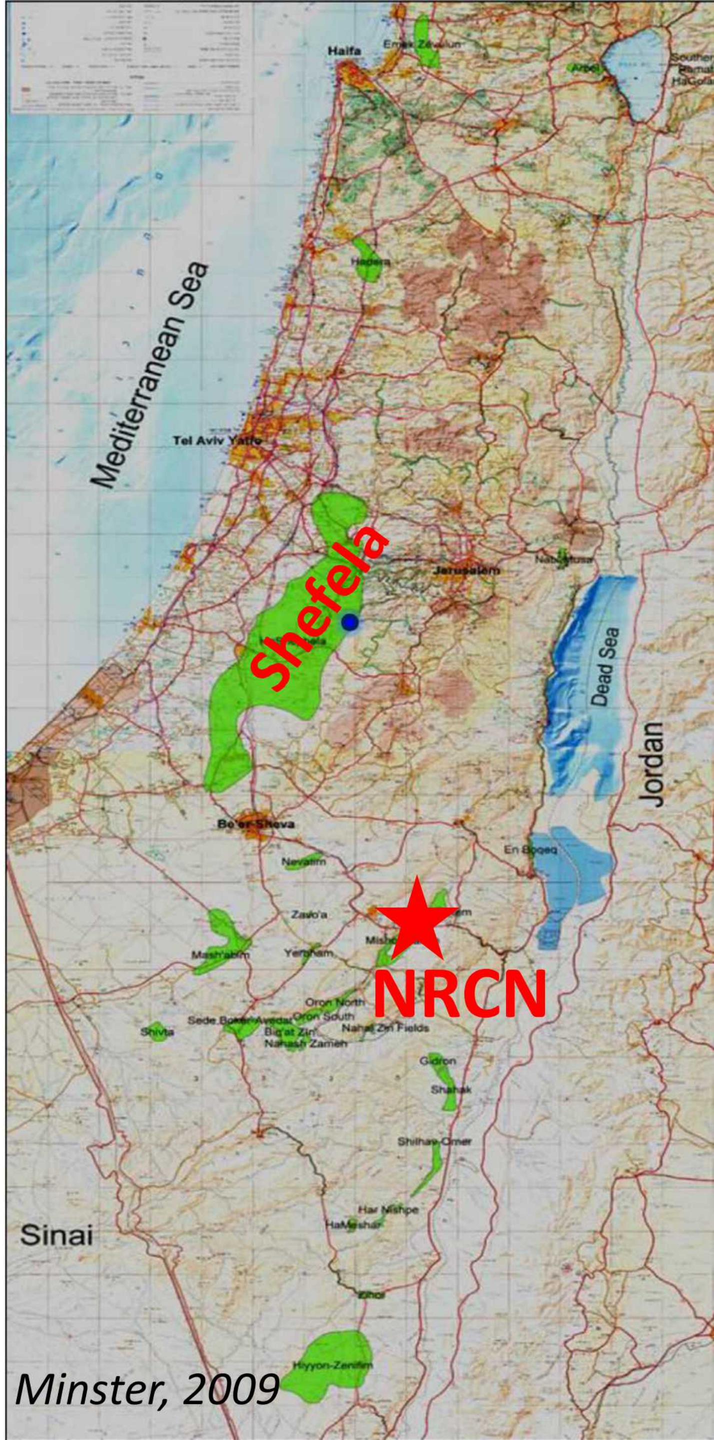


Fig. 7. Peak stress difference plotted vs. depth in the Zoharim well, confining pressures are given in Table 3.

Shitrit et al., 2016

At elevated temperatures > 270^{0}C rock properties change significantly due to decomposition of the organic matter
Shitrit et al., 2017



Minster, 2009

Chalk response to THM conditions is complex

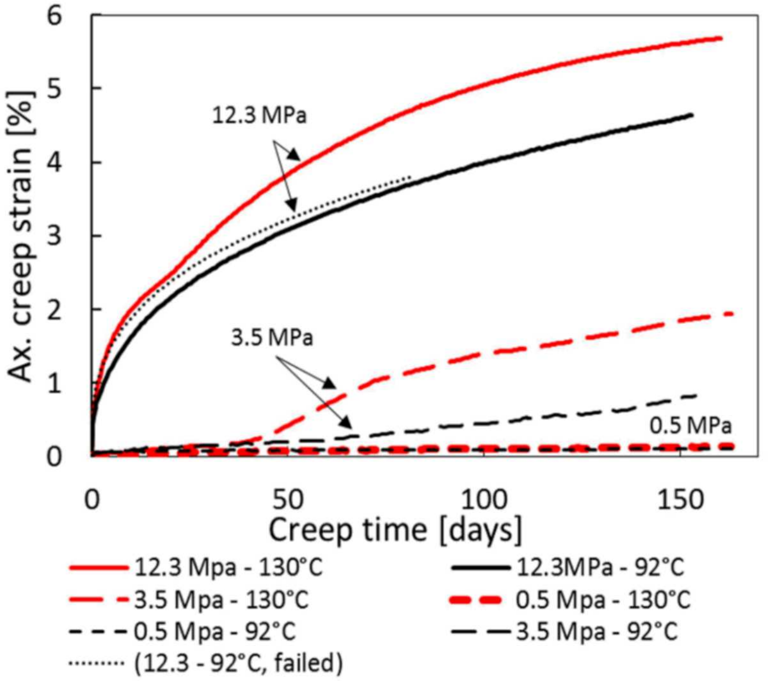
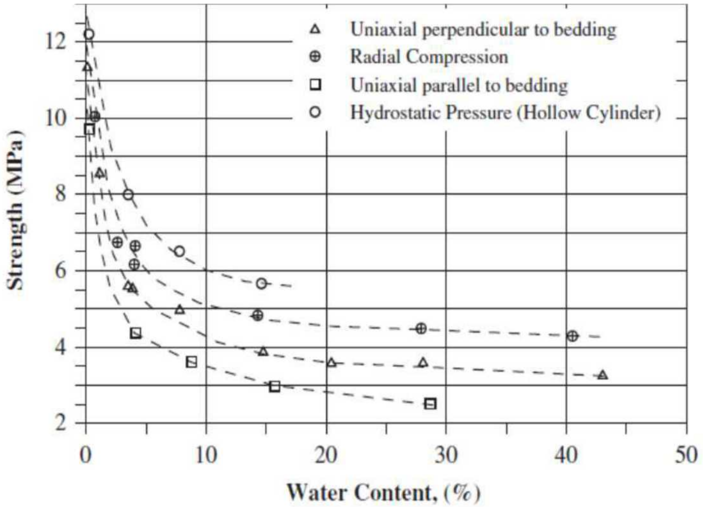
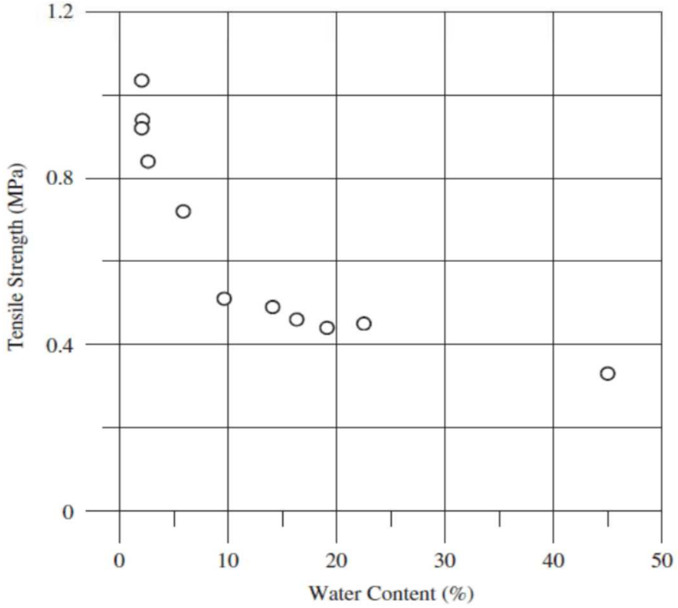


FIGURE 3 | Axial creep strain curve with time for 130and 92◦C temperatures, and 0.5, 3.5, and 12.3MPa effective stresses. In addition, a failed test performed at 12.3 and 92◦C is included to display the repeatability of creep experiments.

chalk





Talenick & Shehadeh, 2007

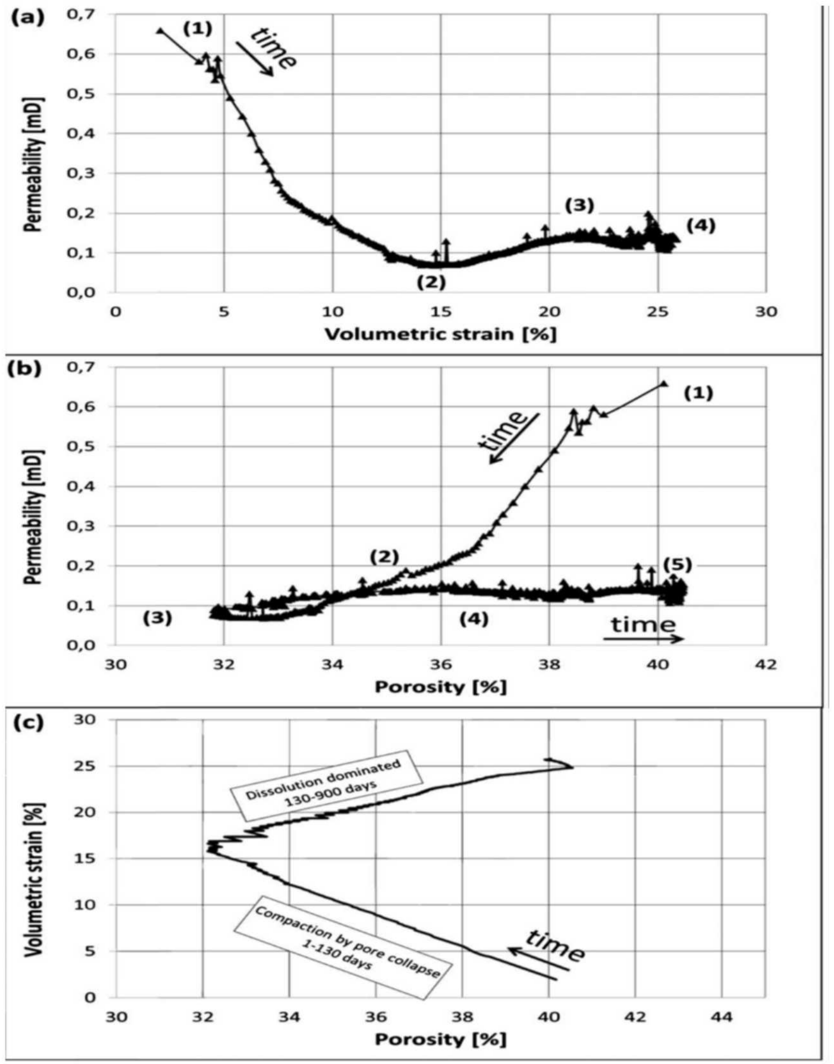
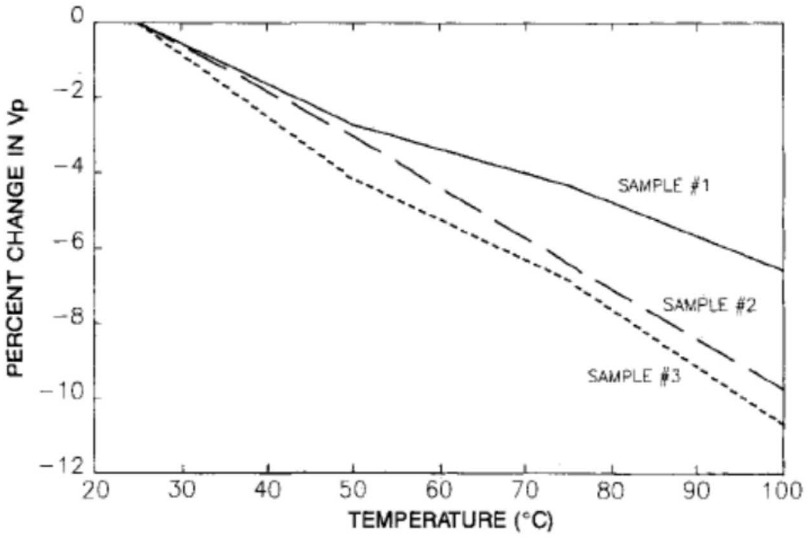


Figure 16. (a) Permeability as a function of volumetric strain 1 at start, 2 at 142 days, 3 at 400 days, and 4 at 1072 days. The permeability is reduced from 1 to 2 as the core compacts. This shifts from 2 to 4 in which the permeability increases despite the core compacts (and dissolves). (b) Measured permeability as a function of estimated porosity throughout the experiment. The numerals 1–5 represent the start, 35 days, 142 days, 550 days, and 1072 days. The permeability and porosity are reduced from1 to 3, while the permeability increases and stabilizes as the porosity increases from 3 to 5. (c) Measured volumetric strain as a function porosity estimate.

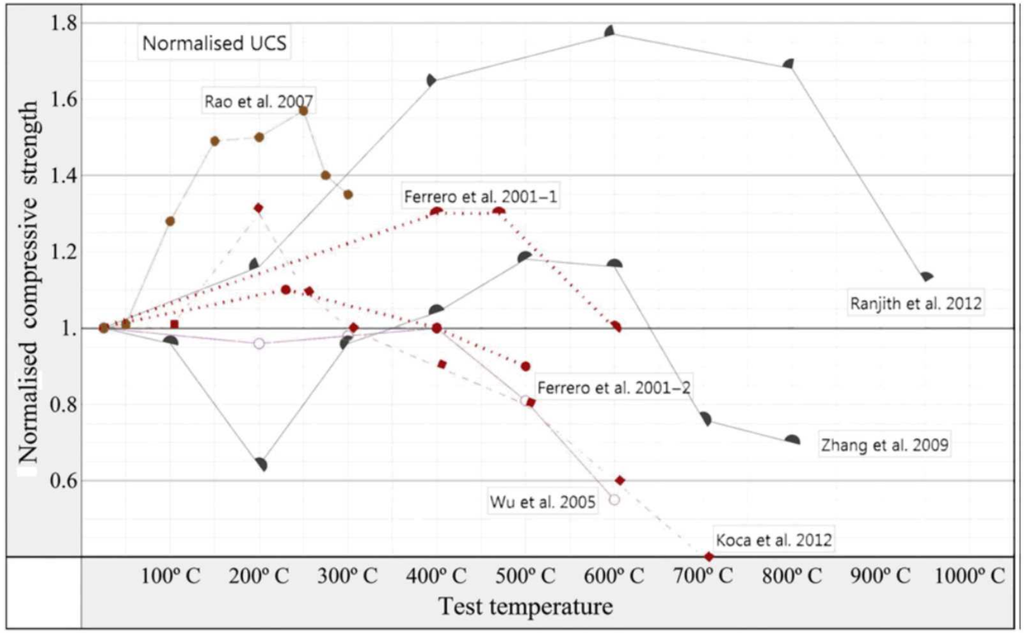
Nermoen et al,2015 chalk

Thermal,Hydrological, and Mechanical (THM) Modelling

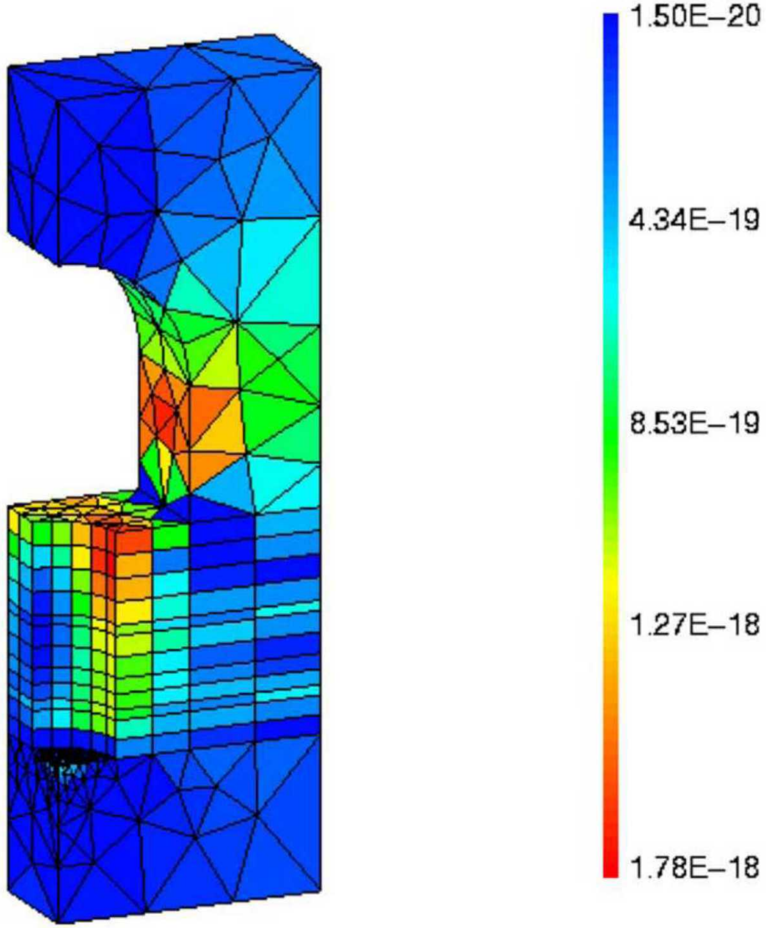


Johnston, 1987

FIG. 13. Changes in *P*-wave velocity as a function of temperature at an effective pressure of about 70 bars. Initial velocities are 3.700 km/s for sample 1, 3.156 km/s for sample 2, and 2.422 km/s for sample 3.



Brotóns et al., 2013 calcarenite



Near-field rock mass permeability after 100 years

Transition to intermediate-depth borehole presents new technical challenges

- GSI, SNL, LLNL: Develop an analysis and lab program based on
  In Situ Conditions + Engineered Conditions
  Prioritize effort implementation
- Support test hole design
- Potential areas for research focus moving forward:
    - Simulation of thermal effects and offgassing on borehole stability and damage.
    - Thermal driven multi-phase flow through natural fractures and casing interfaces.
    - Micromechanical modeling and experimental investigation of permeability changes with thermal effects
    - Coupled fracture flow and geochemistry analysis

Work at LLNL will benefit from ongoing efforts under out exascale computing program to develop a capability for field-scale borehole fracture/flow simulations with ultra-high resolution of the fracture process zone.