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Damage Induced by Excavation and Heat Release of a Radioactive Waste Repository

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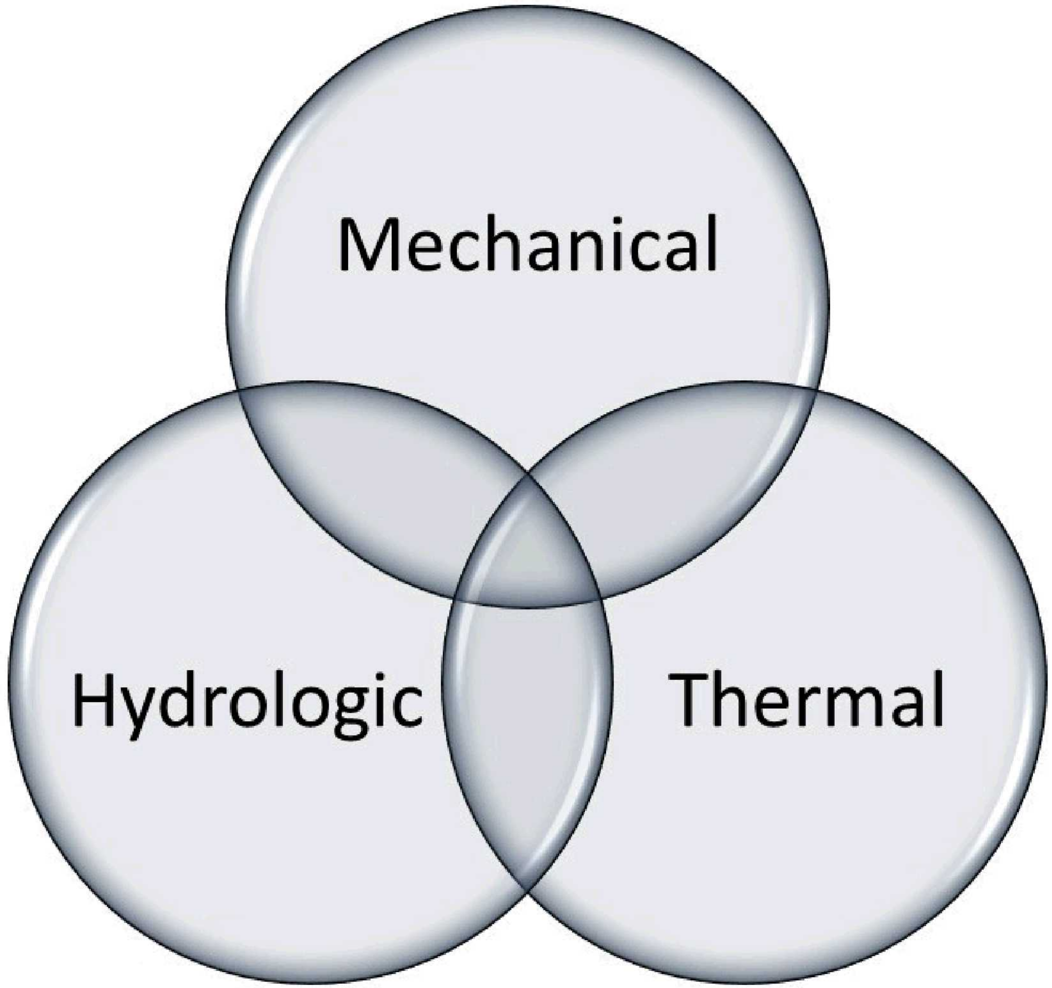
Tasks

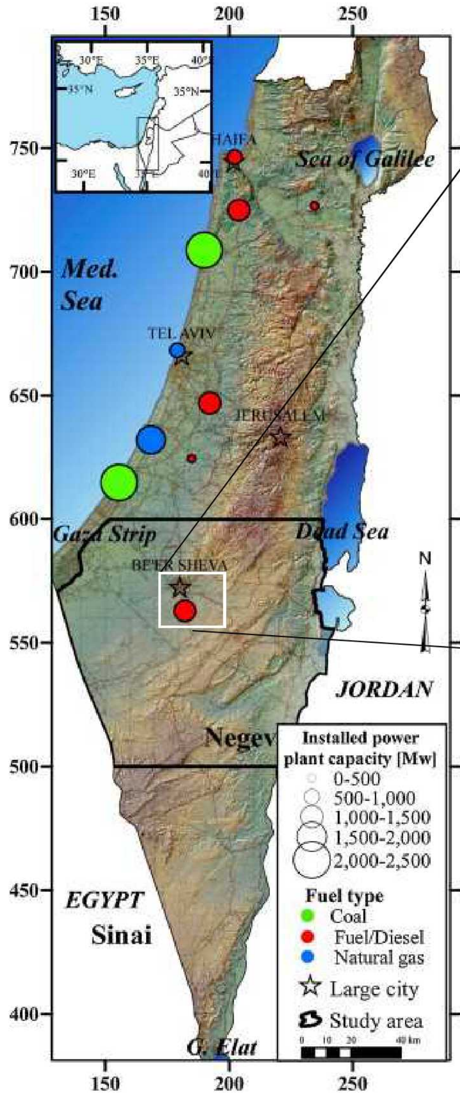
	2017	2018	2019
Task 1: Modeling Damage Created by Excavation			
Task 2: Experimental study of the **mechanical** and **transport properties** for dry and saturated rock samples			
Task 3: Non-isothermal damage-porosity visco-elastic rheological model			
Task 4: Experimental study of **thermal properties**			
Task 5: Modeling Damage Created by Heat			
Task 6: Long Term Modeling Damage Evolution of Radioactive Waste Repository			
Task 7: Code Modernization and Parallel Execution			

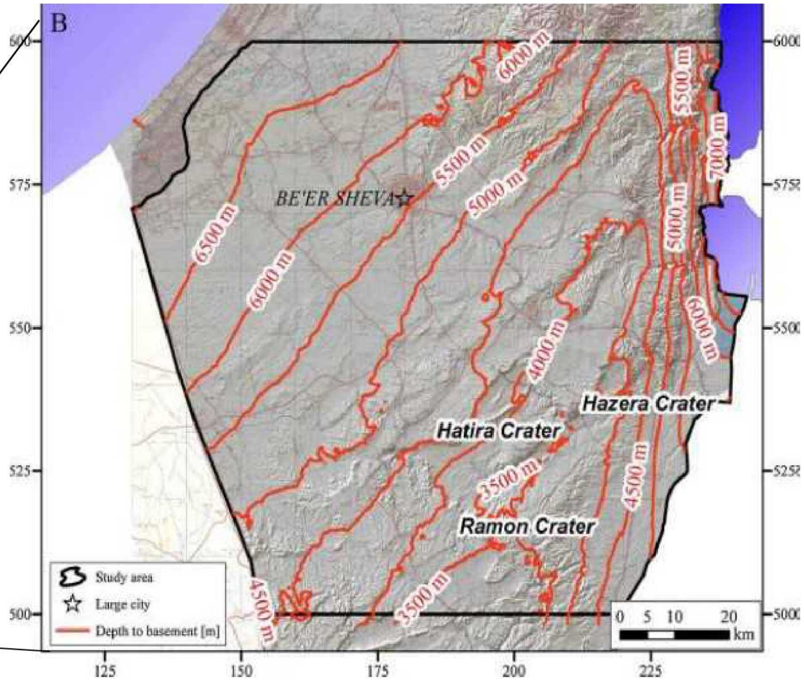
Damage induced by:

- Excavation
- Heat



Coupled nature of operative processes





Depth of Zenifim formation

(Calvo & Gvirtzman, 2013)

Depths of interest: 3-5 km;
70-100MPa confining pressure
Temperatures: ambient to 300C
Dry, water-saturated

lithic-arkosic coarse sandstone
50% feldspar (oligoclase-andesine)
40% quartz,
10% lithics, biotite, chlorite, hornblende
(Weissbrod & Sneh 2002)

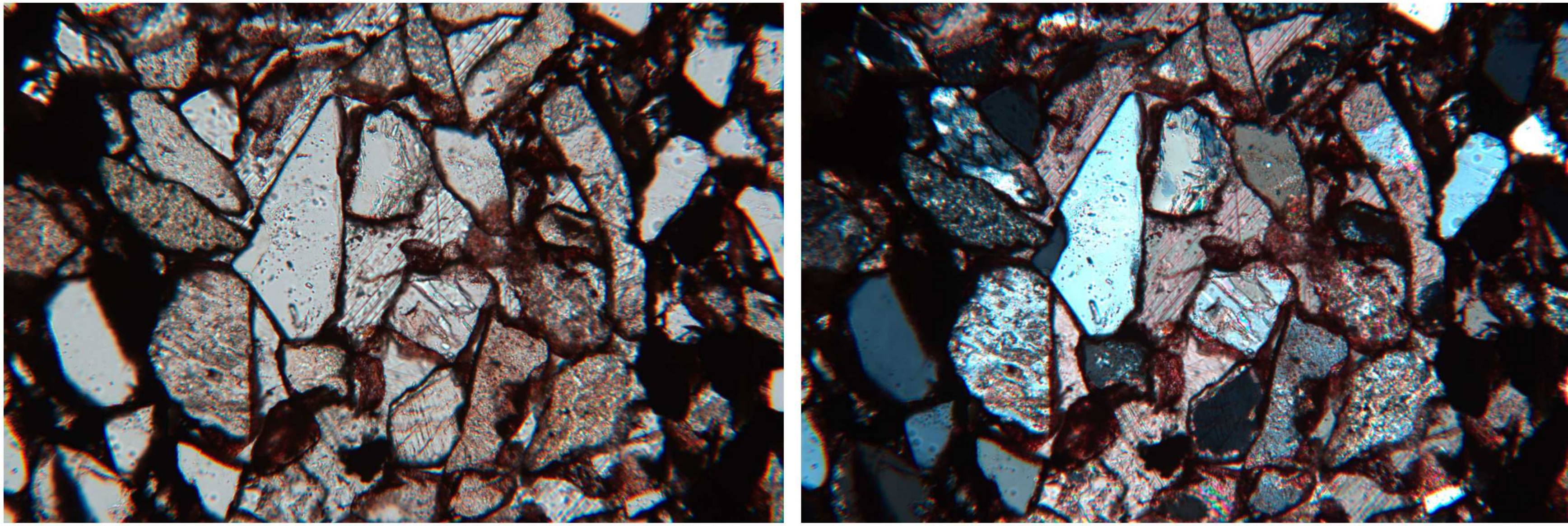
Target Horizon: Late Precambrian Zenifim Fm.

Rock Core transfer to Sandia

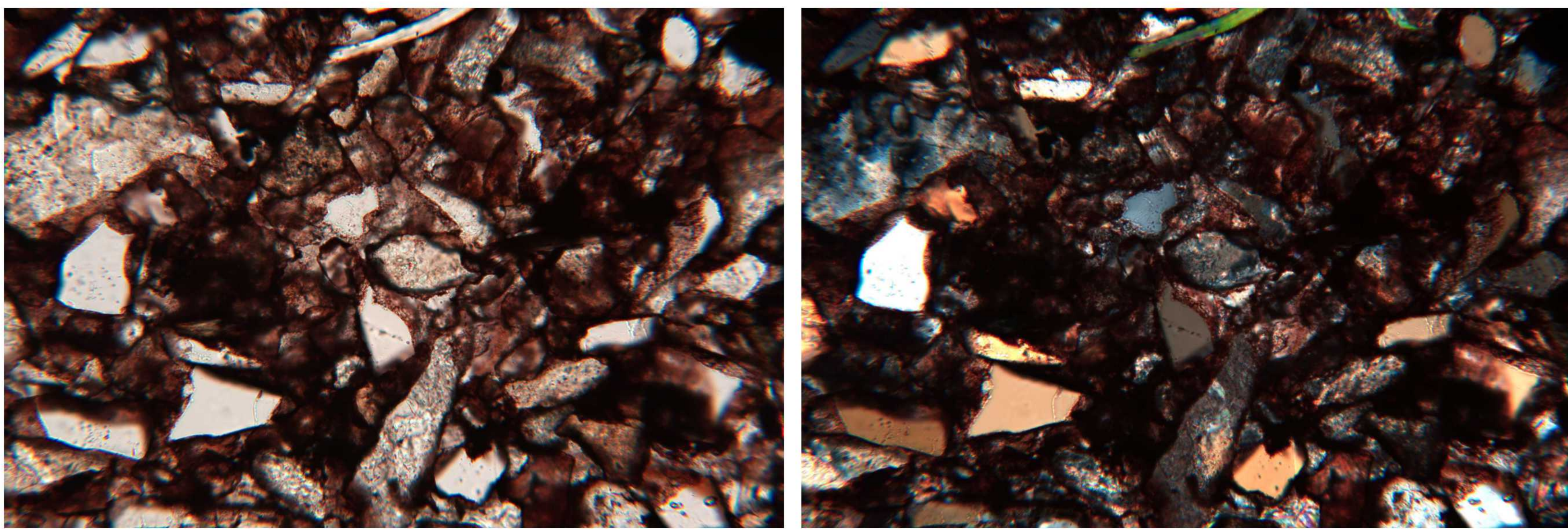
Mechanical,
Hydrologic,
Thermal
property determinations

Shortcoming to project:
Limited sample availability

Mineralogy and Cementation

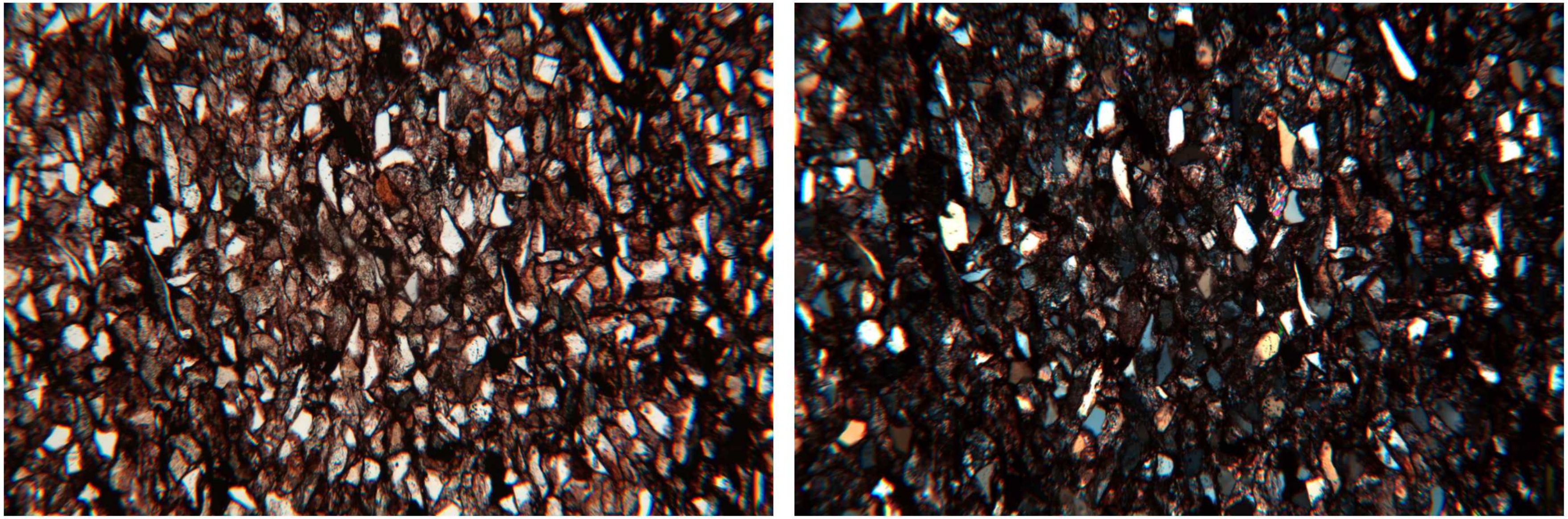


Plane light (left) and plane-polarized light (right) images of feldspar, quartz, magnetite, lithic fragments, and mica flakes cemented by calcite. Almost all grains are coated with a thin hematite layer. Field of view = 0.800mm. Loading direction is vertical, sample IR-29-1.

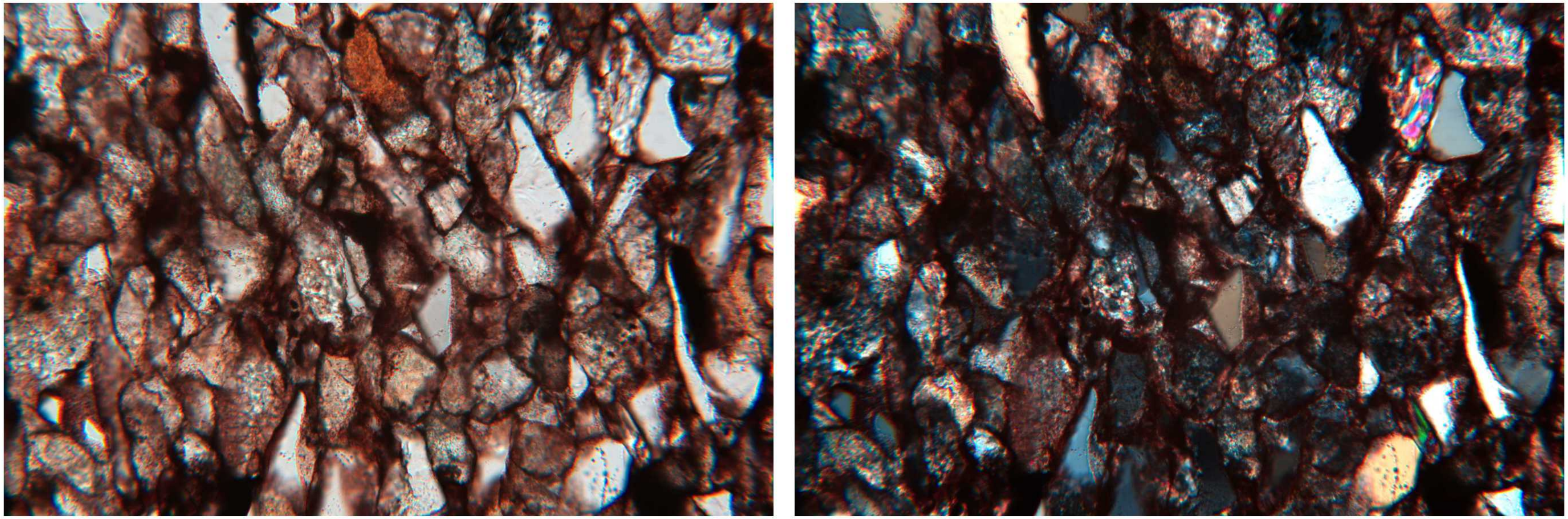


Plane light (left) and plane-polarized light (right) images of feldspar, quartz, lithic fragments, magnetite and other opaques, mica flakes, and hornblende in a fine-grained matrix of hematite, chlorite, and clays. This fine-grained matrix without obvious cementation is more common than calcite cement shown above. Field of view = 0.800mm. Loading direction is vertical, sample MK2-1 C29 B2e.

Anisotropy: Grain Alignment



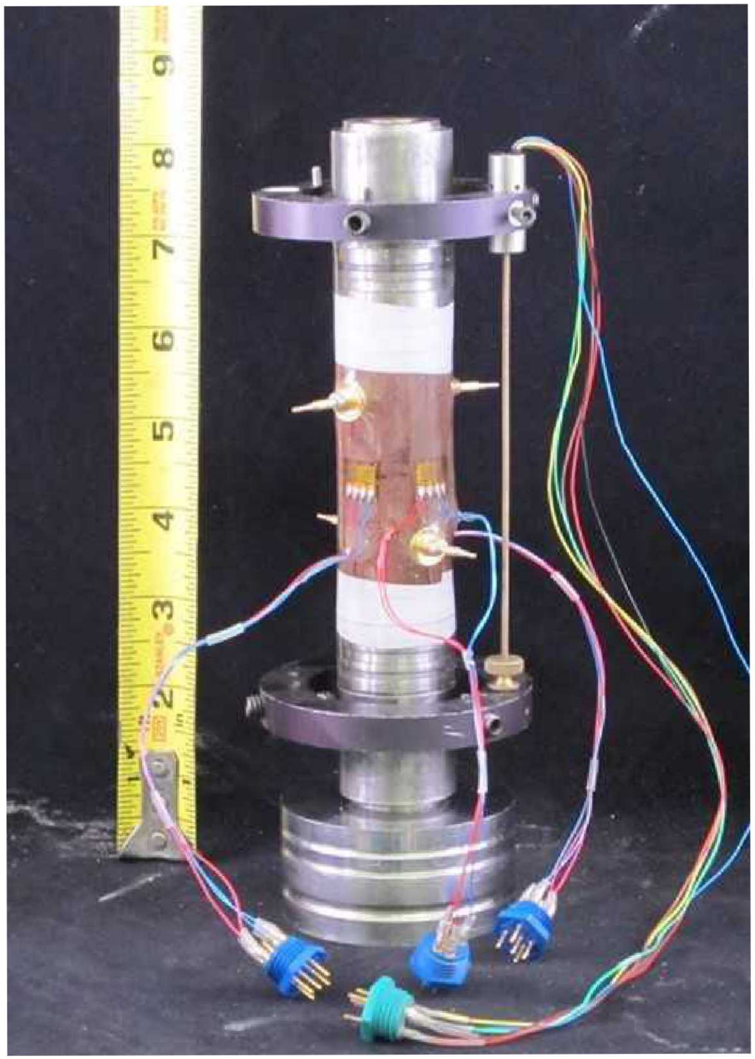
Plane light (left) and plane-polarized light (right) images of grain alignment, accentuated by elongate quartz, feldspar, and mica constituents. Field of view = 2.043mm. Loading direction is vertical, sample IR-29-3.



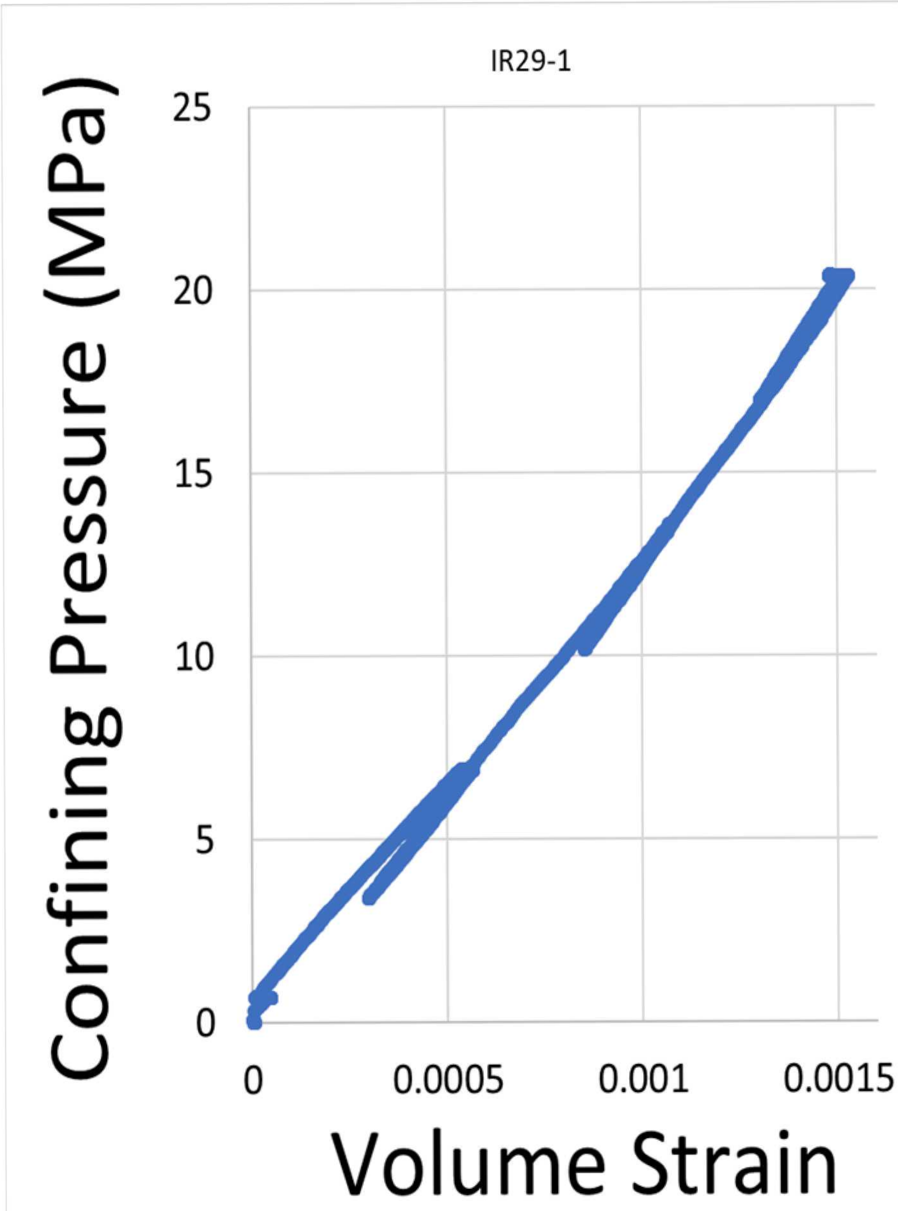
Plane light (left) and plane-polarized light (right) images of grain alignment, accentuated by elongate quartz, feldspar, and mica constituents. Field of view = 0.800mm. Loading direction is vertical, sample IR-29-3.

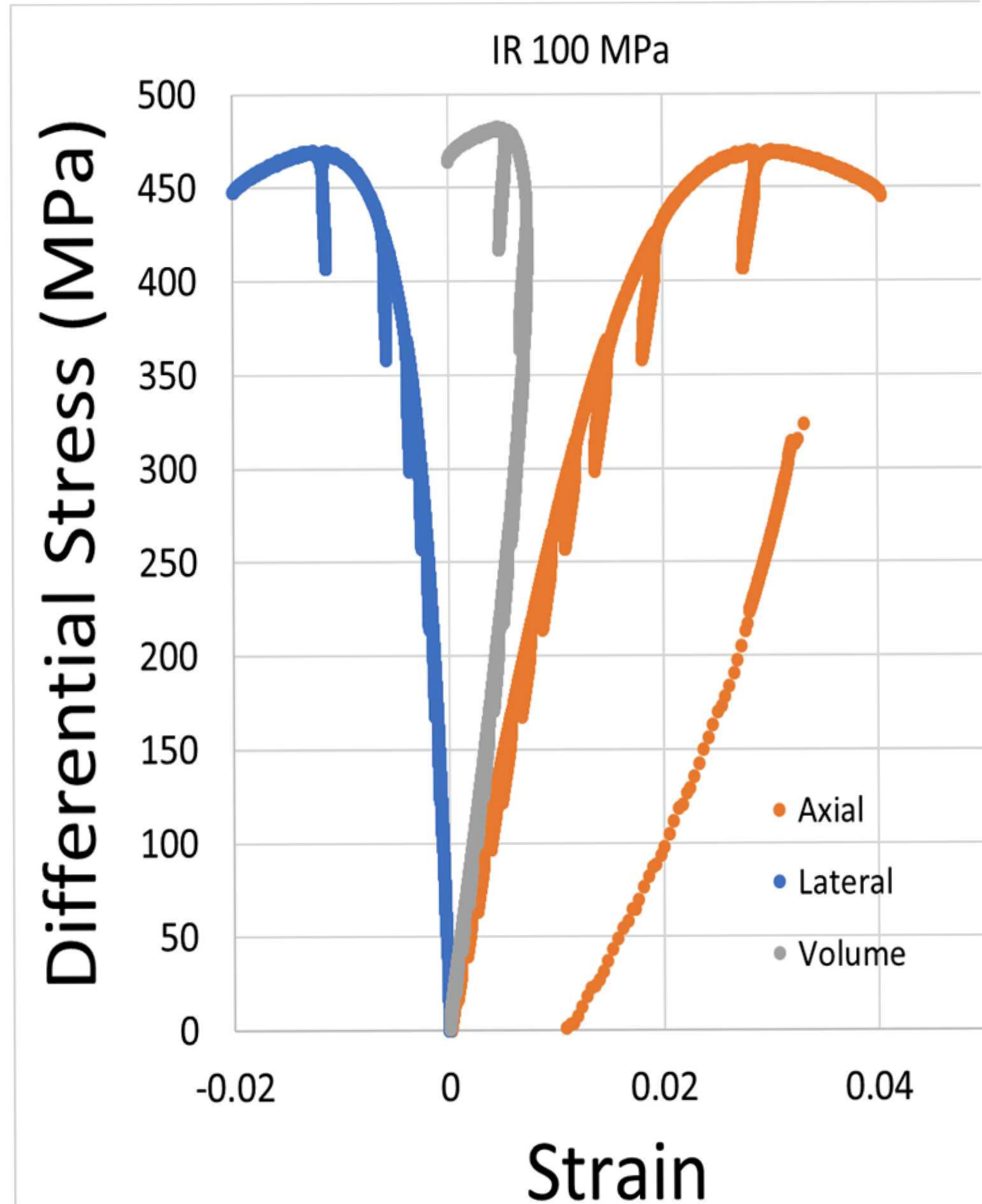
Elastic and Strength Properties

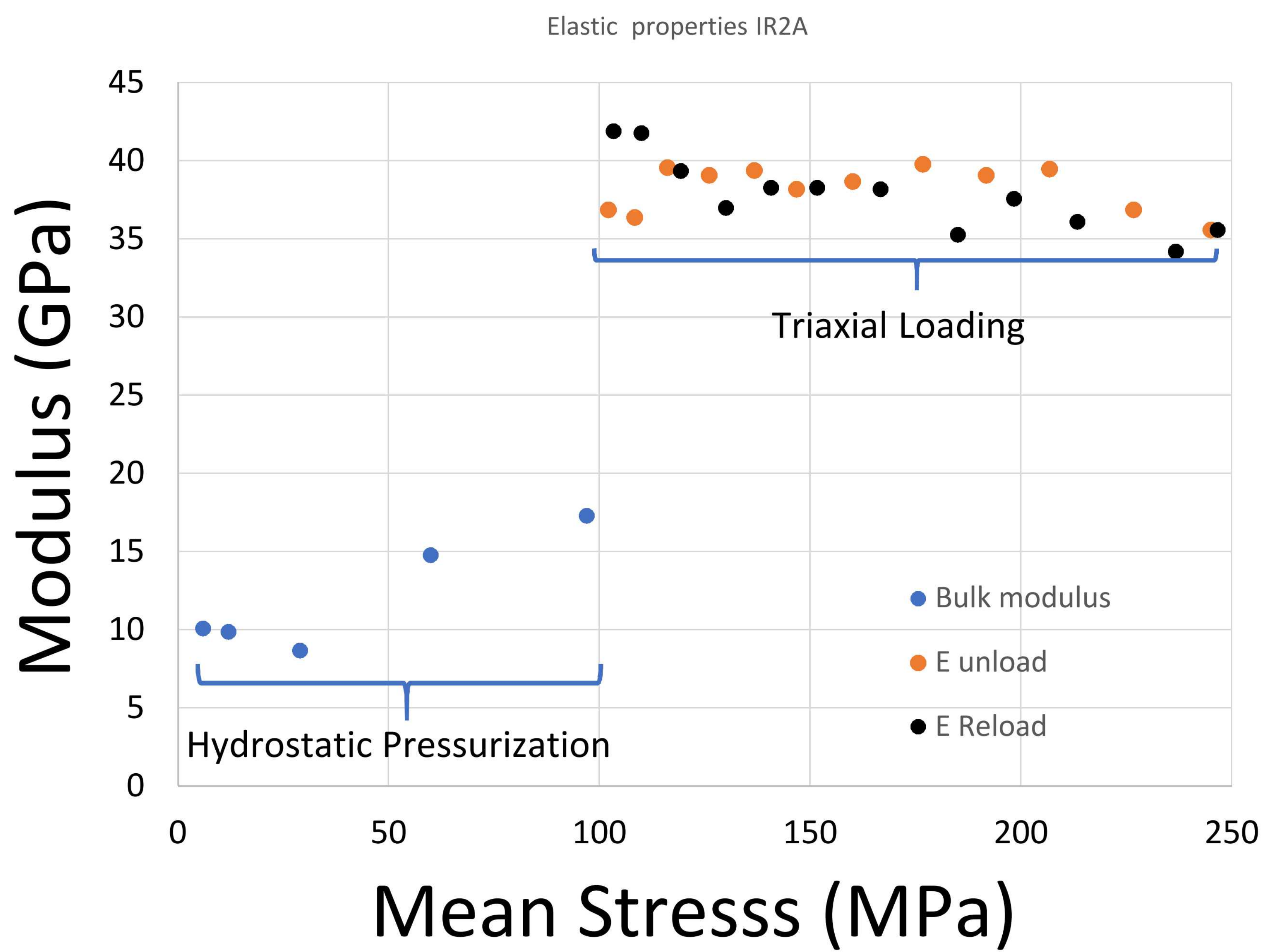
σ, E, β, strength criterion: f(temperature,
pressure,
strain/stress)

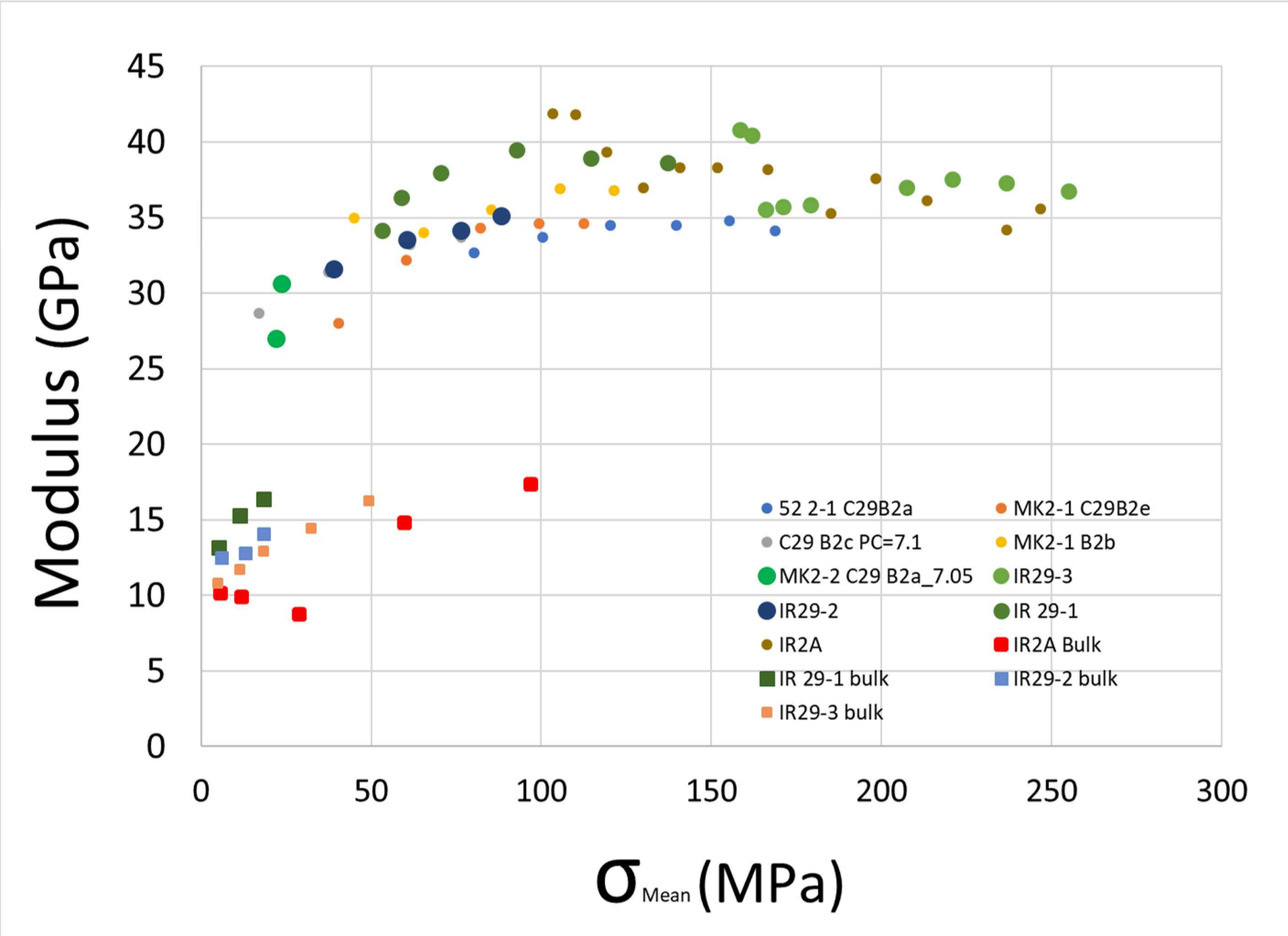


Example data

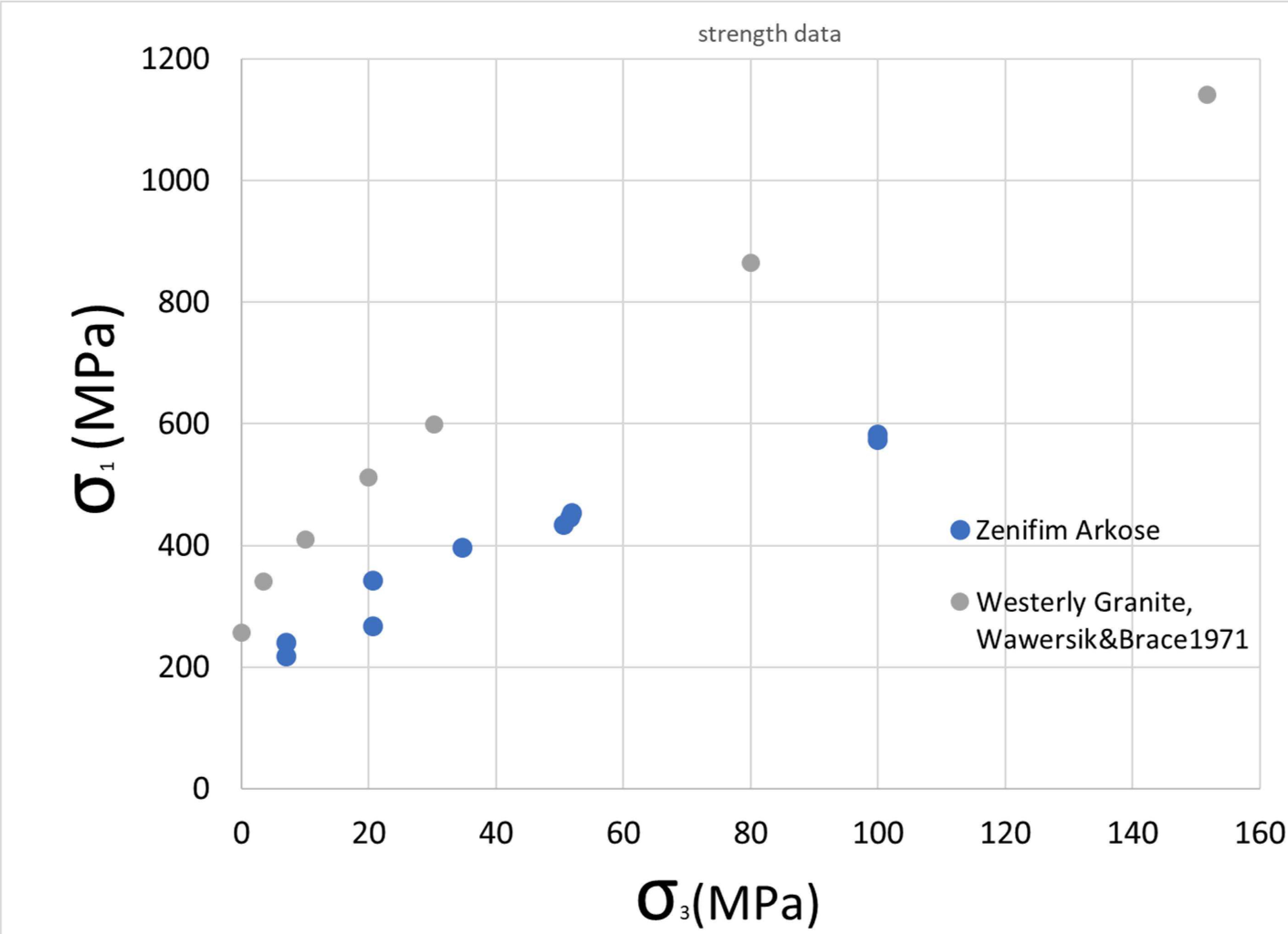





Elastic properties IR2A
Modulus (GPa)
45
40
35
30
25
20
15
10
5
0
0
50
100
150
200
250
Mean Stresss (MPa)
Triaxial Loading
Hydrostatic Pressurization
Bulk modulus
E unload
E Reload

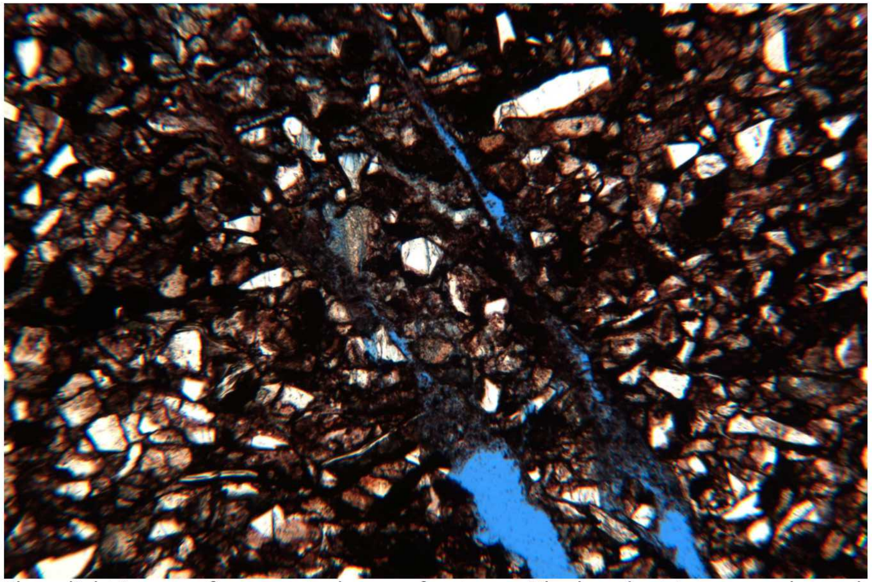


Modulus (GPa)
45
40
35
30
25
20
15
10
5
0
0
50
100
150
200
250
300
σ Mean (MPa)
52 2-1 C29B2a
MK2-1 C29B2e
C29 B2c PC=7.1
MK2-1 B2b
MK2-2 C29 B2a_7.05
IR29-3
IR29-2
IR 29-1
IR2A
IR2A Bulk
IR 29-1 bulk
IR29-2 bulk
IR29-3 bulk

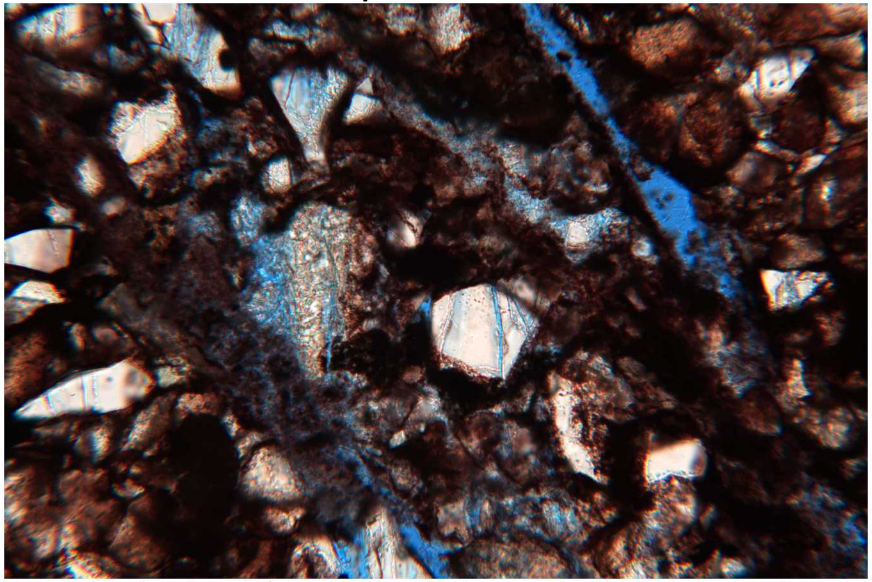


strength data
1200
1000
800
600
400
200
0
0
20
40
60
80
100
120
140
160
σ_1 (MPa)
σ_3(MPa)
Zenifim Arkose
Westerly Granite,
Wawersik&Brace1971

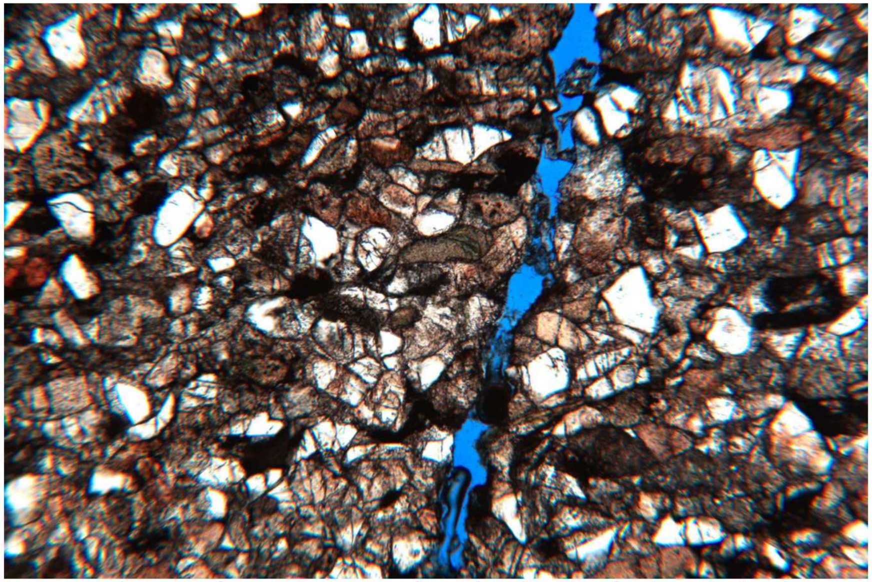
Microfracture-Macrofracture Relationships



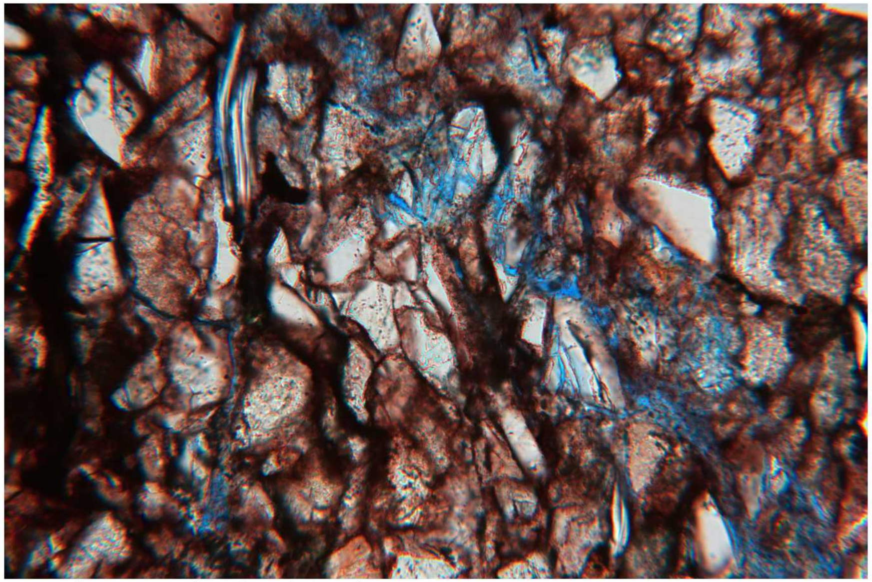
Plane light image of segmented macrofracture with abundant intragranular and transgranular microfractures in zone in between segments. Field of view = 2.043mm. Loading direction is vertical, sample MK2-2 C29 B2b.



Zoomed-in view from left image, showing increased microfracture density adjacent to macrofractures. Field of view = 0.800mm. Loading direction is vertical, sample MK2-2 C29 B2b.

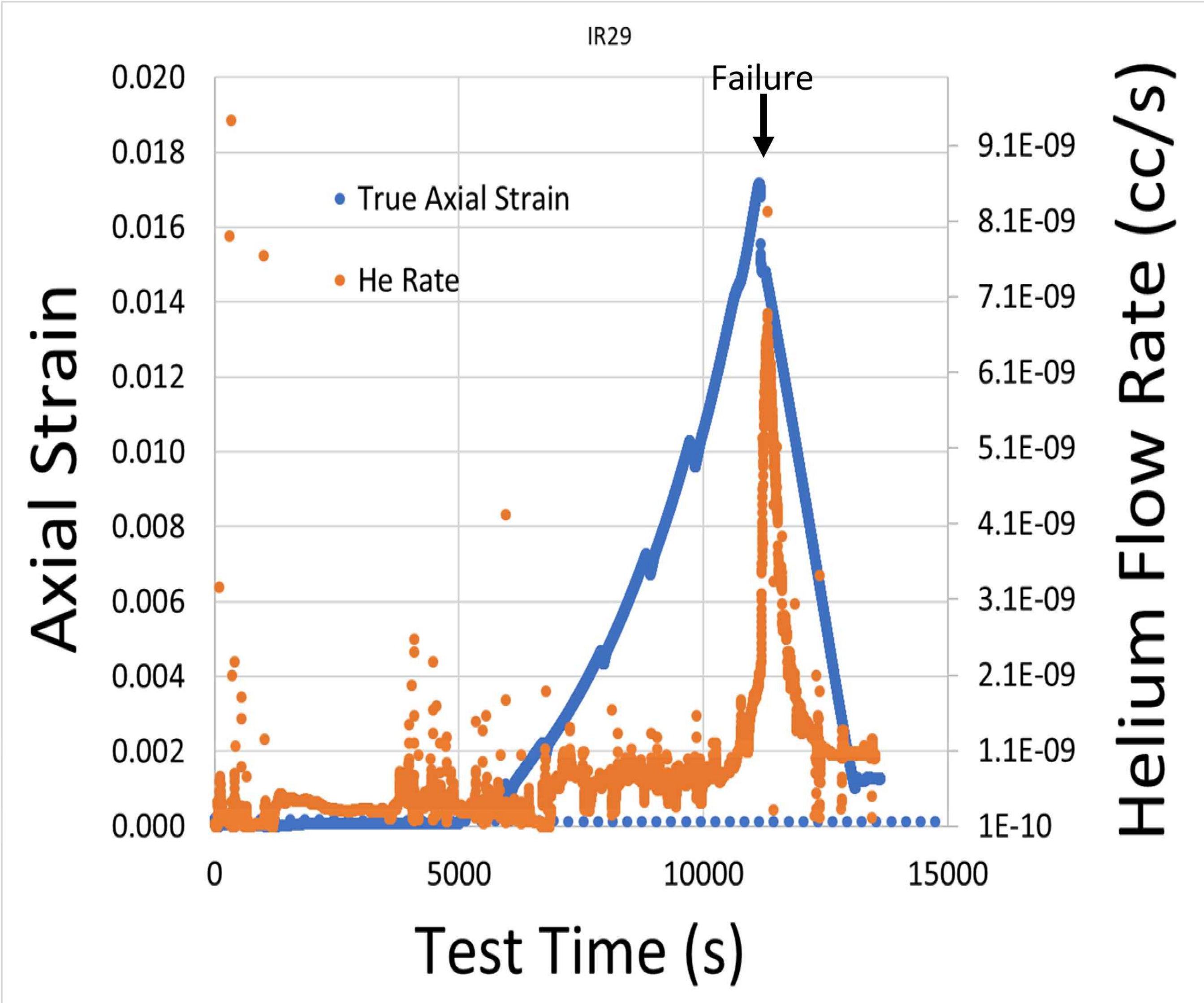


Intragranular microfractures are not aligned with macrofracture, instead are parallel to long axis of thin section (loading direction). Field of view = 2.043mm. Loading direction is vertical, sample IR-TG.



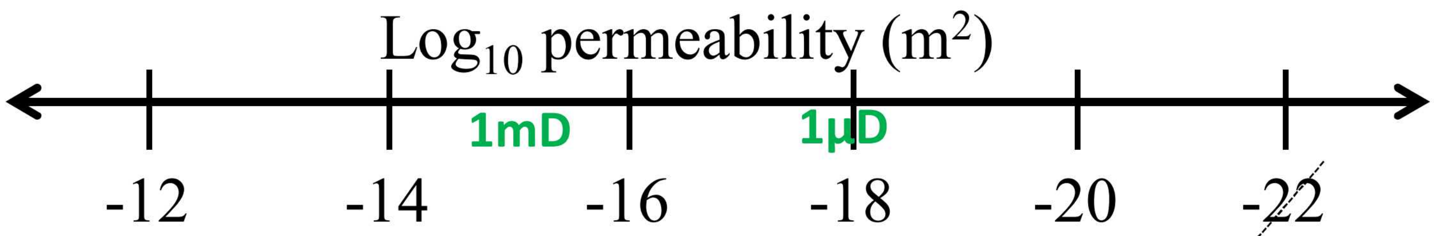
Macrofractures often break into lower-aperture segments or numerous transgranular microfractures, with no apparent connection to bedding or grain alignment variations. Field of view = 0.800mm. Loading direction is vertical, sample IR-29-3.

Real-time Noble Gas Release

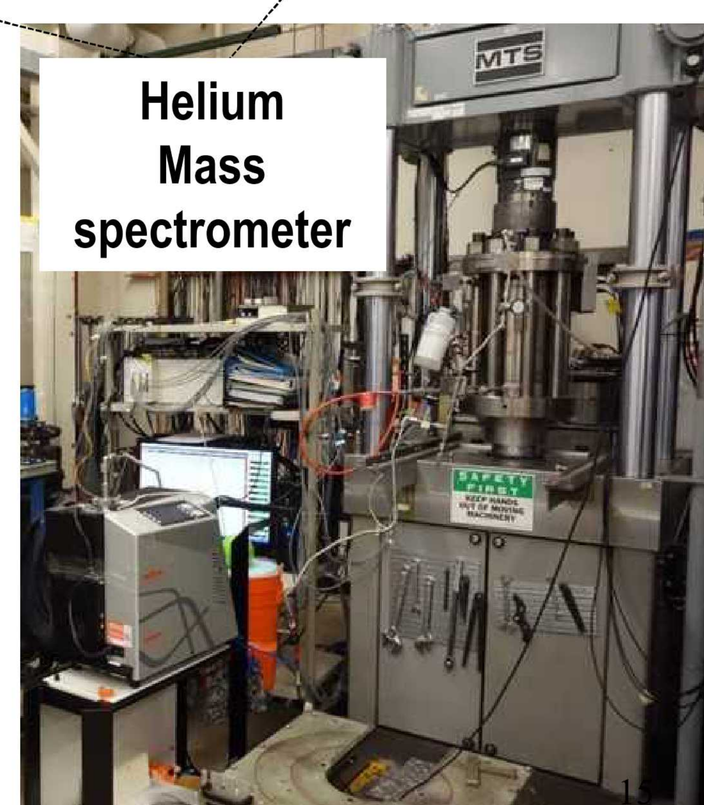


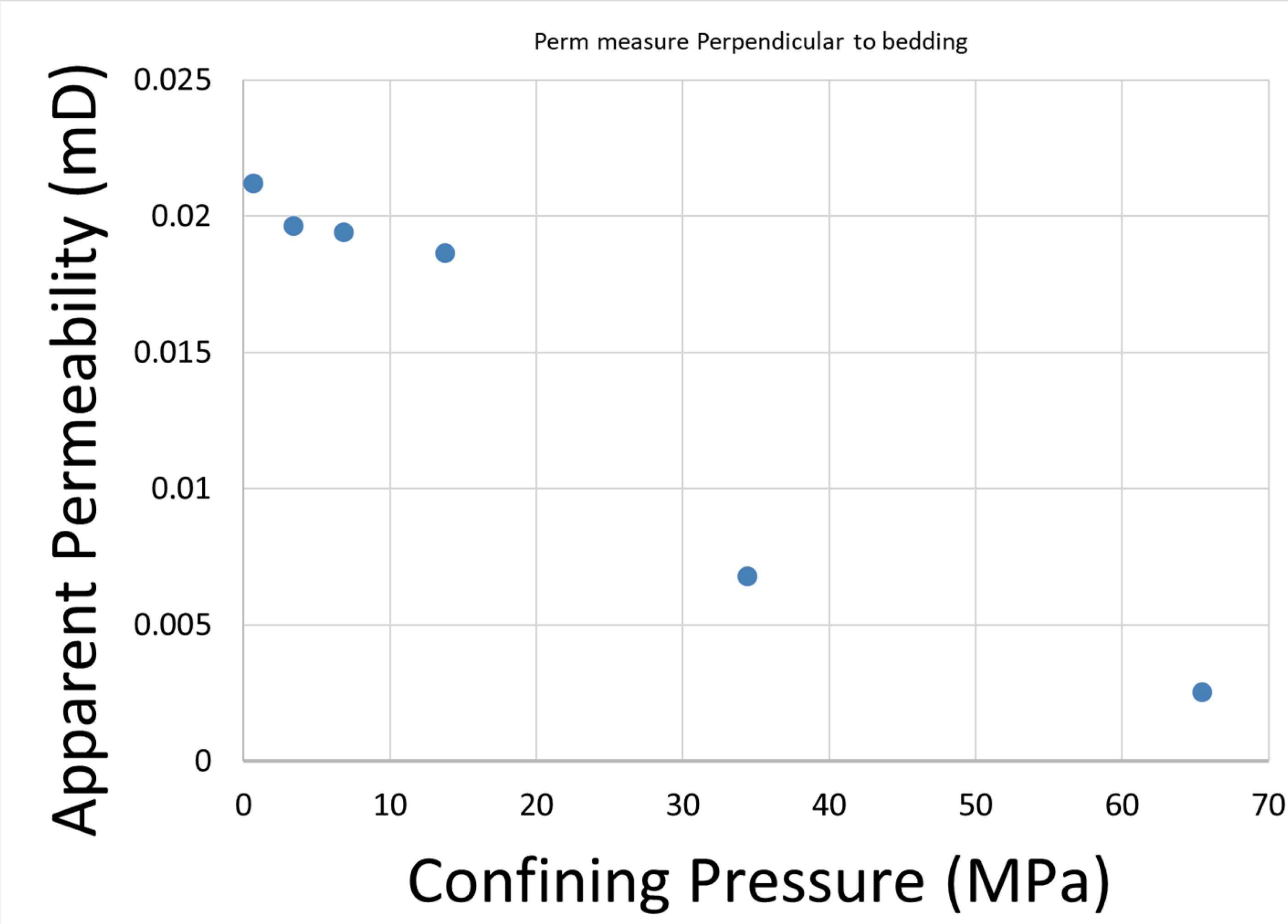
Hydrologic Properties

Porosity, Permeability: f(pressure, temperature, deformation)



Flowmeters





Perm measure Perpendicular to bedding
Apparent Permeability (mD)
0.025
0.02
0.015
0.01
0.005
0
0
10
20
30
40
50
60
70
Confining Pressure (MPa)

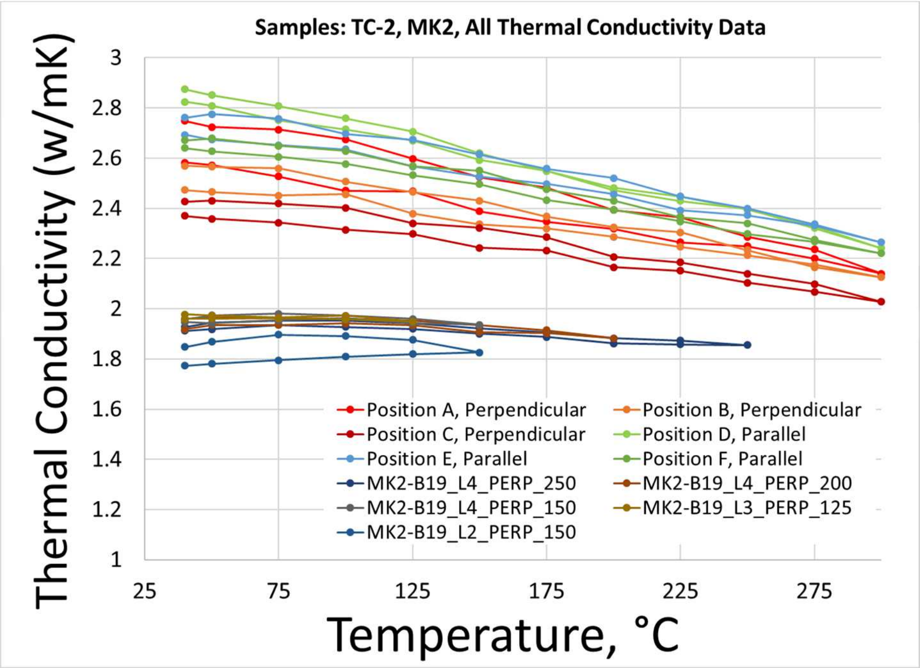
Thermal Properties

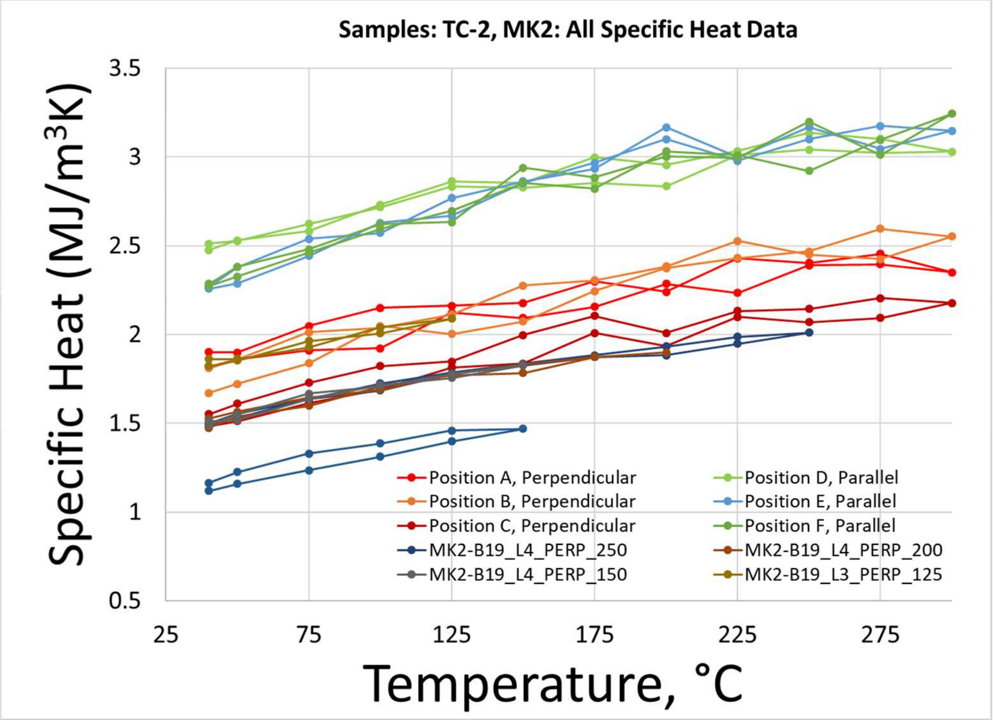
Conductivity: (W/mK) the property of a material to conduct heat

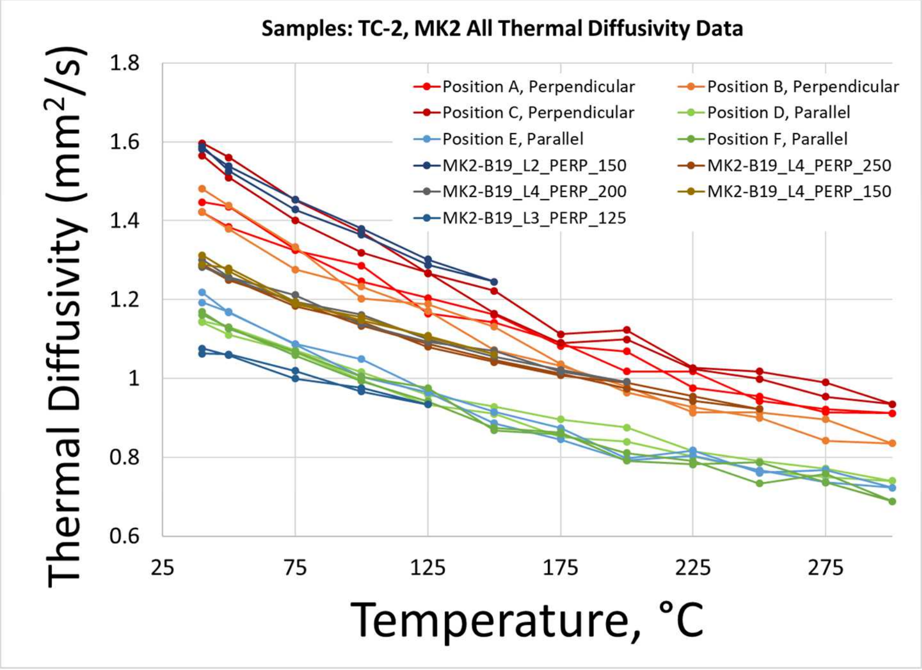
Diffusivity: (mm^2/s) measure of thermal inertia

Specific Heat: (MJ/m^3K) the amount of heat per unit mass required to raise the temperature by 1 ^oC

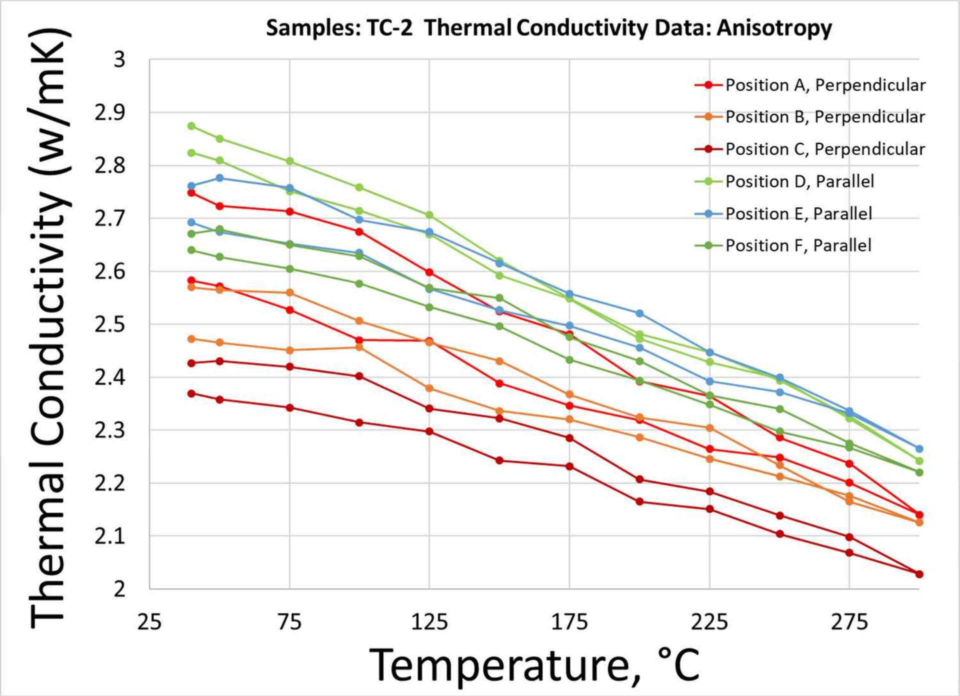
Thermal Properties All Data

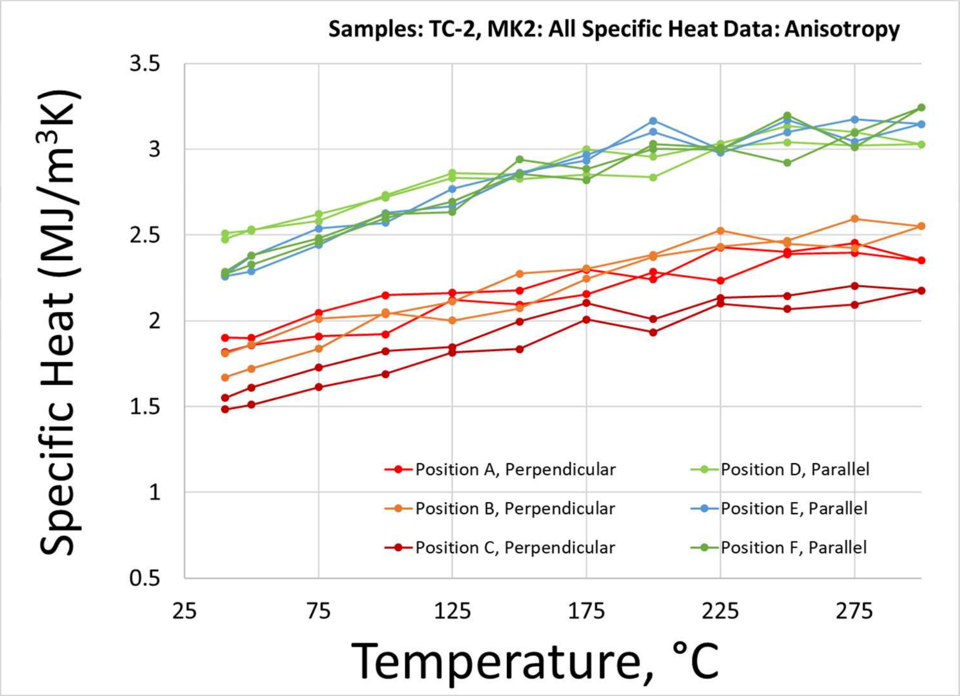


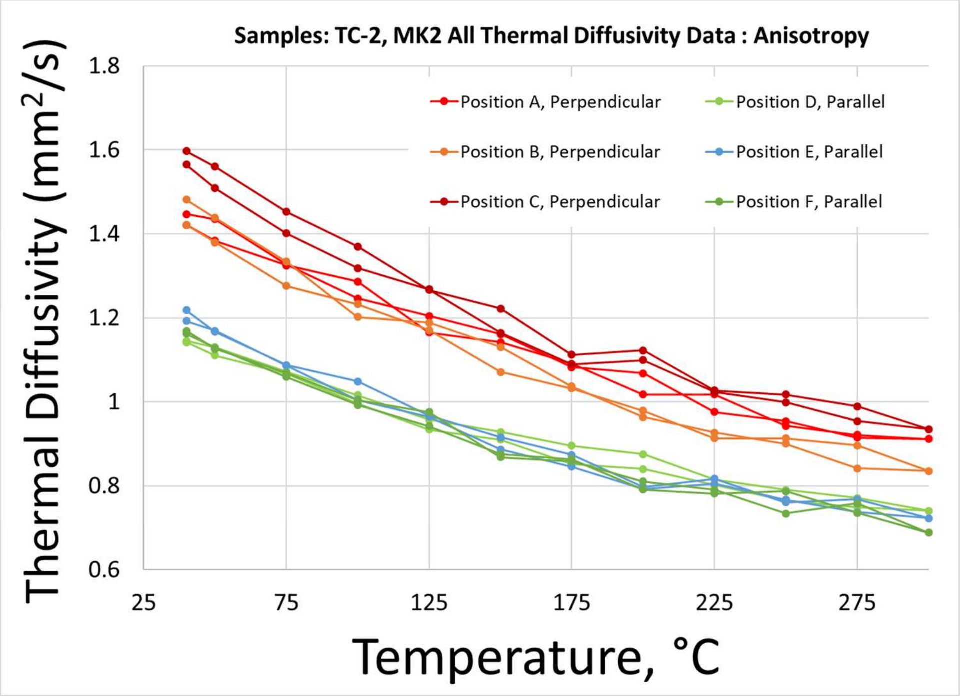


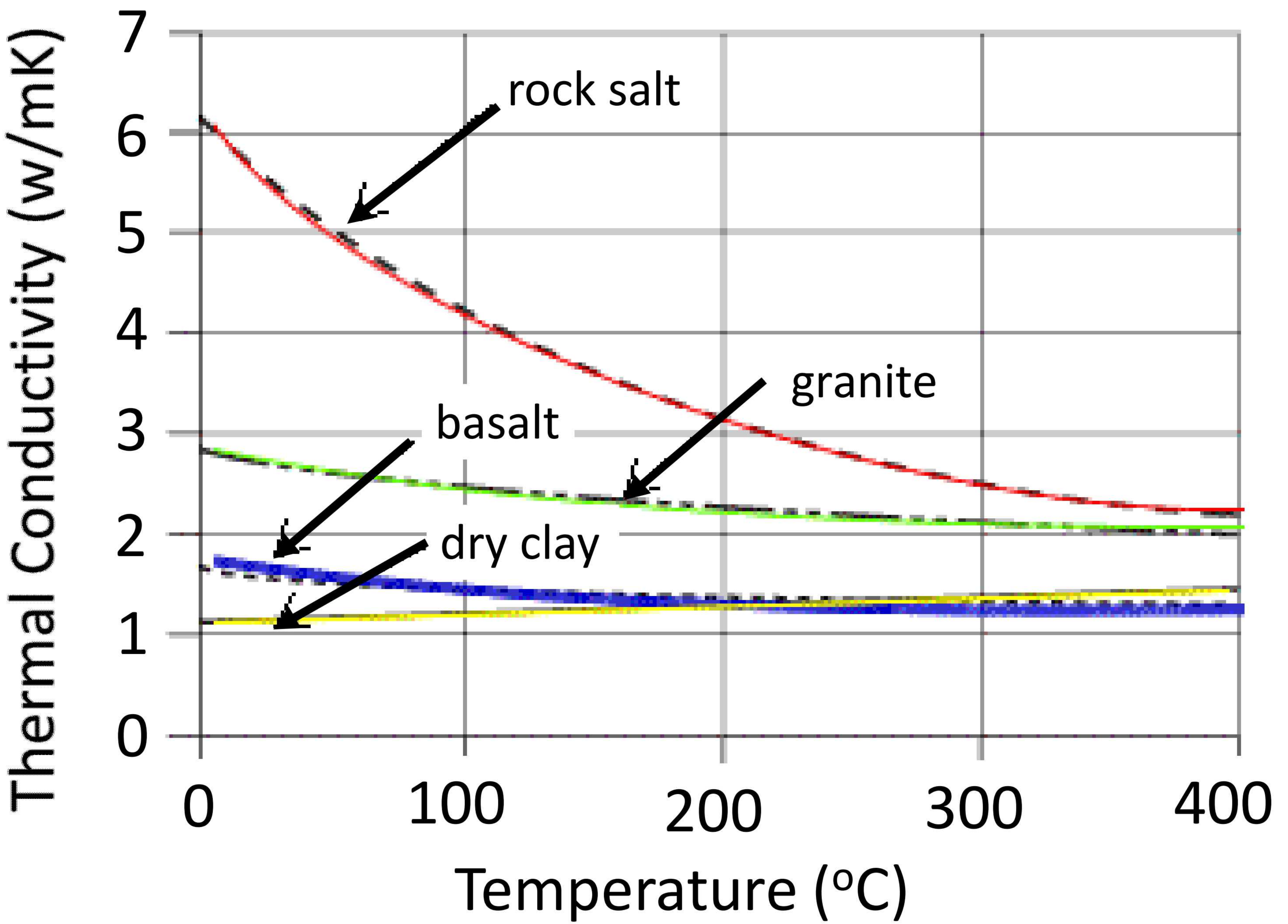


Thermal Properties: Anisotropy

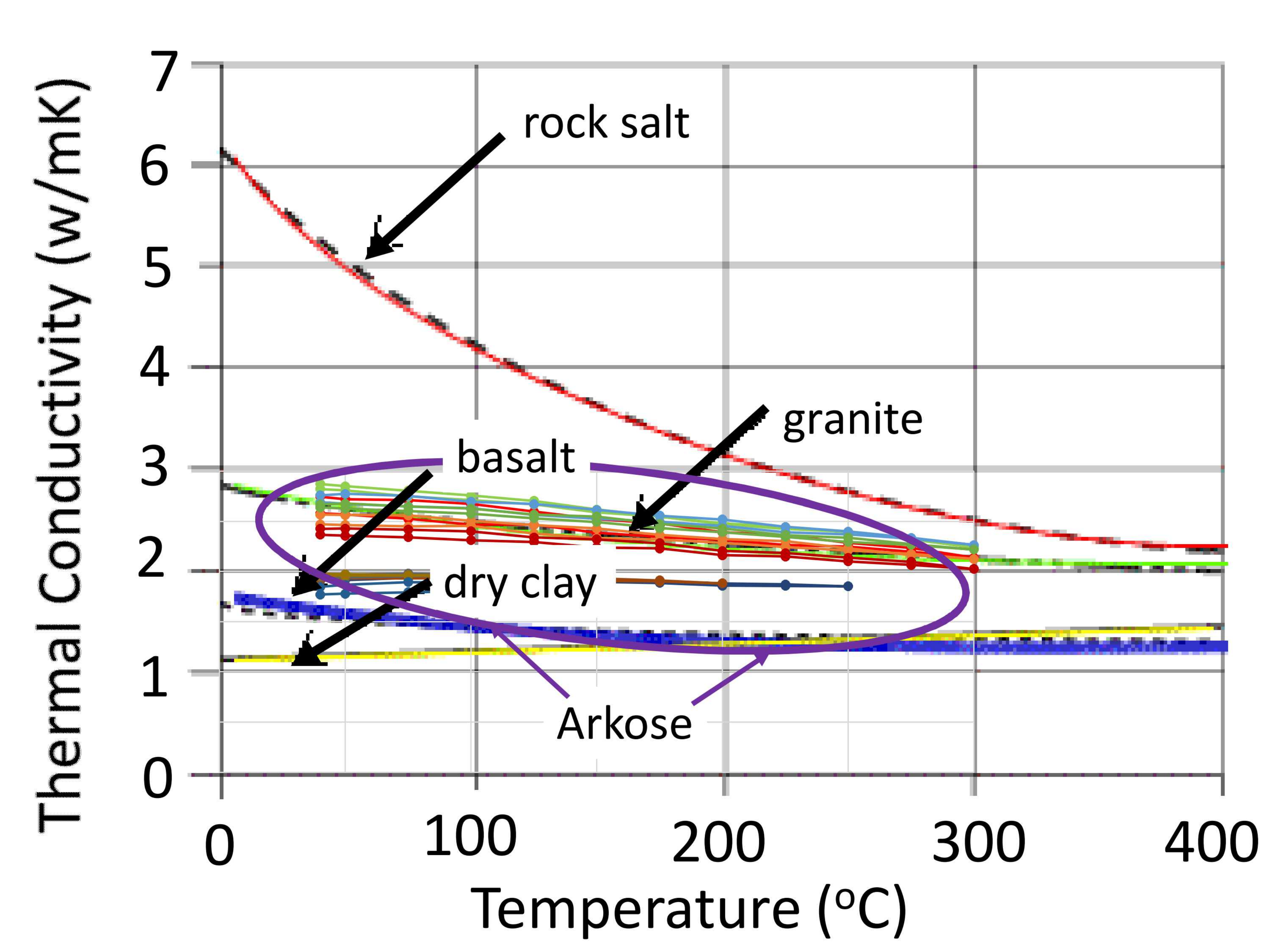








Thermal Conductivity (w/mK)
7
6
5
4
3
2
1
0
rock salt
granite
basalt
dry clay
0
100
200
300
400
Temperature (oC)



Thermal Conductivity (w/mK)
7
6
5
4
3
2
1
0
0
100
200
300
400
Temperature (°C)
rock salt
granite
basalt
dry clay
Arkose

Summary

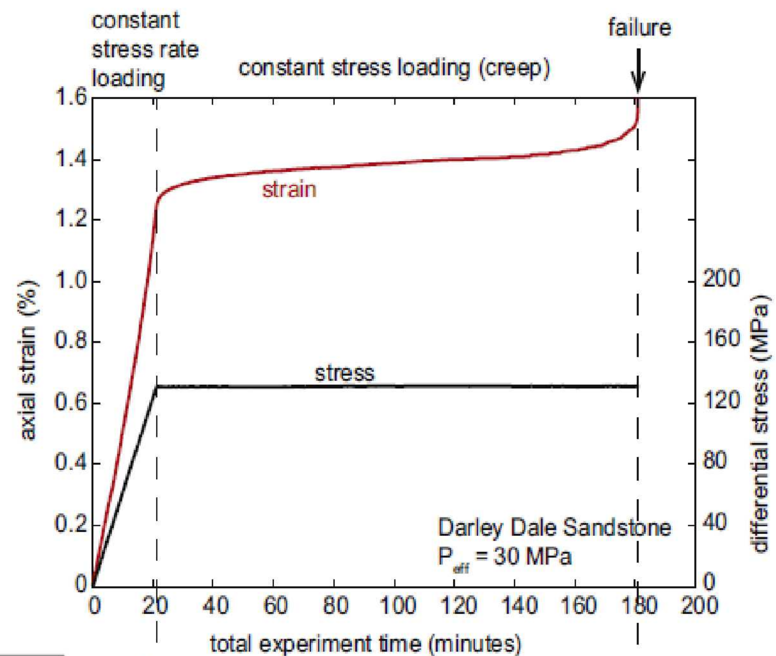
- Compressive strength testing nearly completed; strength arkose < granite
- Strength, elastic properties not anisotropic (minimal study); arkose softer than granite
- Elastic properties pressure and deformation dependent (probably more so than granite)
- Observations completed to support experimental work
- Permeability low, decreases with increasing pressure
- Noble gas release during deformation observed, potential tool in the future
- Thermal properties anisotropic, plenty of variability
- Thermal conductivity similar to granite

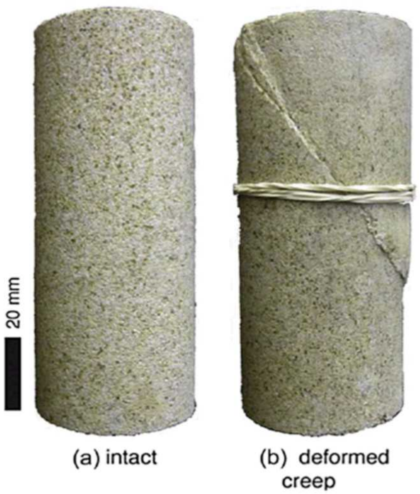
Future work (this year and next)

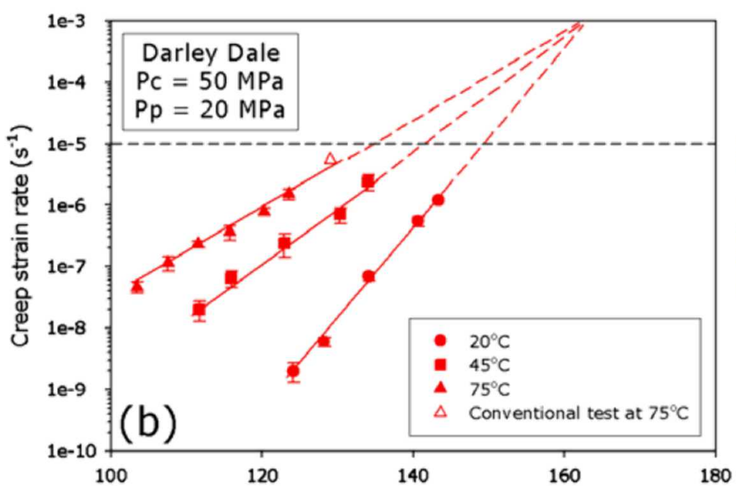
1-Document results (planned paper with GSI, LLNL)
2-Continue/complete quasi-static testing to include more permeability measurements and permeability measurements post fracture
3-Time-dependent (Creep) testing to support model development (GSI/LLNL)
4-Tests at elevated temperature
5-Petrofabric analyses to support acoustic emission and damage model development

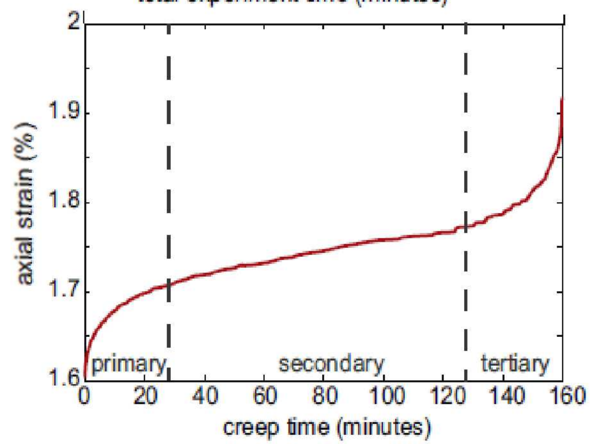
This year: Constant Load Creep Tests; temperature effects for Zenifim

- Conduct brittle creep experiments
- Samples deformed at constant stress, not constant displacement/strain rate
- Failure time varies based on load, confining pressure
- Use acoustic emissions to monitor damage development during creep





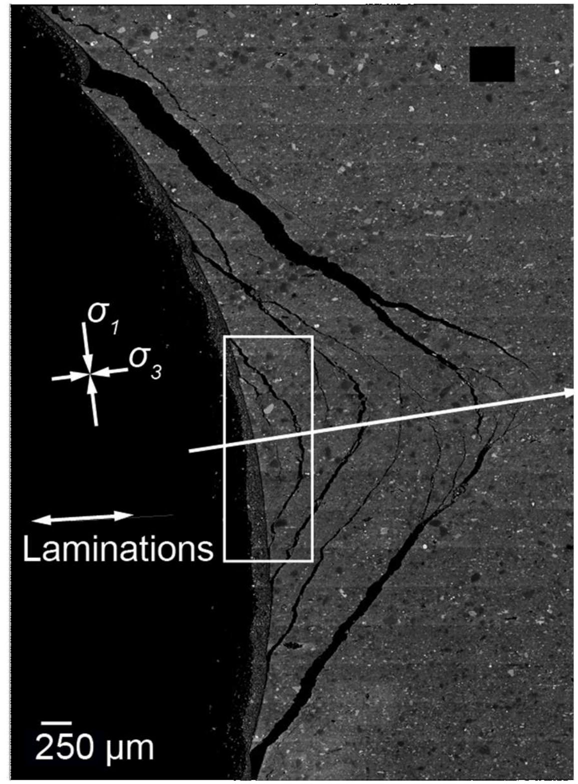


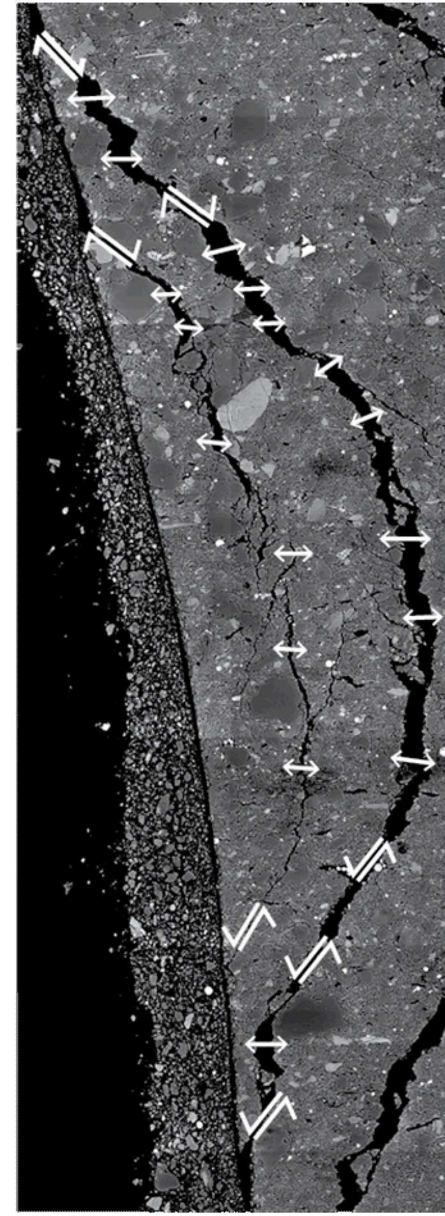


Darley Dale SS

Heap et al., 2009, Brantut et al., 2013

Lab studies of borehole breakouts

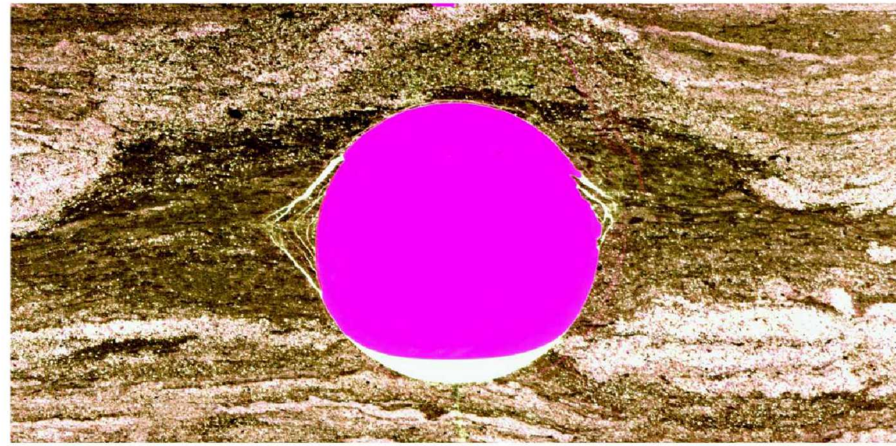




- Investigate bedding effects upon borehole breakout
- 3 sample orientations: parallel, perpendicular, and 45° to bedding
- Clear variations in borehole strength, mechanism

Orientation of borehole, stresses, anisotropy are important to nature of breakout formation and growth

PERP 1.1



PARA 1.1

45D 1.1

Test Matrix

Test Type	Bedding Orientation	Confining Pressure (MPa)	Temperature (°C)	Acoustic Emission	Permeability
Creep	Perpendicular	7	Ambient	Yes	No
Creep	Perpendicular	20	Ambient	Yes	No
Creep	Perpendicular	100	Ambient	Yes	No
Creep	Perpendicular	200	Ambient	Yes	No
Creep	Parallel	50	Ambient	Yes	No
Creep	Parallel	200	Ambient	Yes	No
Constant Rate	Perpendicular	20	75	Yes	No
Constant Rate	Perpendicular	100	75	Yes	No
Constant Rate	Perpendicular	200	75	Yes	Yes
Constant Rate	Perpendicular	20	225	No	No
Constant Rate	Perpendicular	100	225	No	No
Constant Rate	Perpendicular	200	225	No	Yes
Constant Rate	Parallel	50	75	Yes	No
Constant Rate	Parallel	200	75	Yes	Yes
Constant Rate	Parallel	50	225	No	No
Constant Rate	Parallel	200	225	No	Yes