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Impact of thermo-mechanical properties on deformation behavior of potential host rock for nuclear waste disposal

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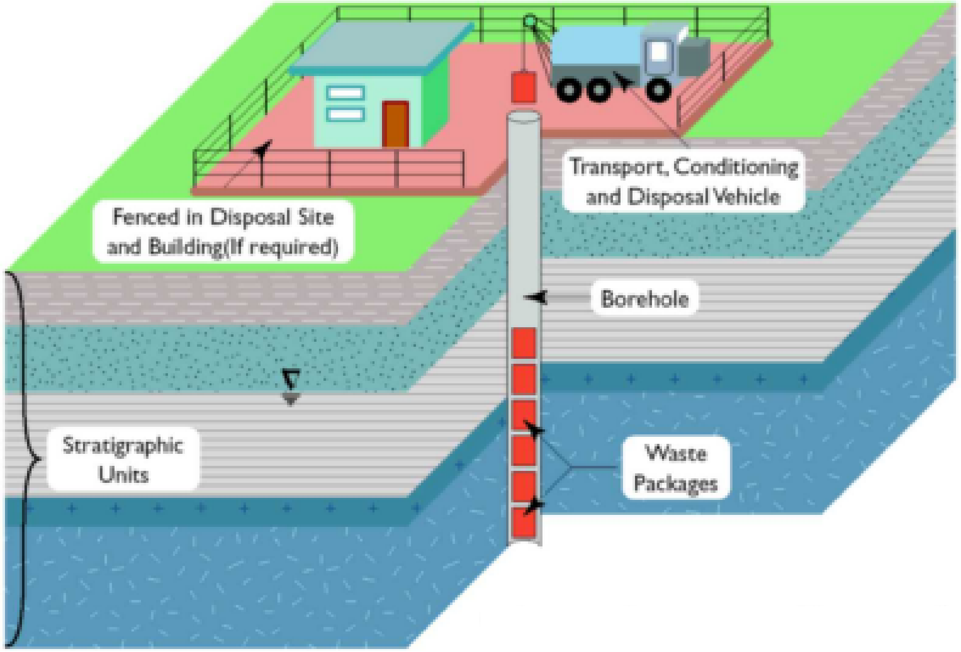
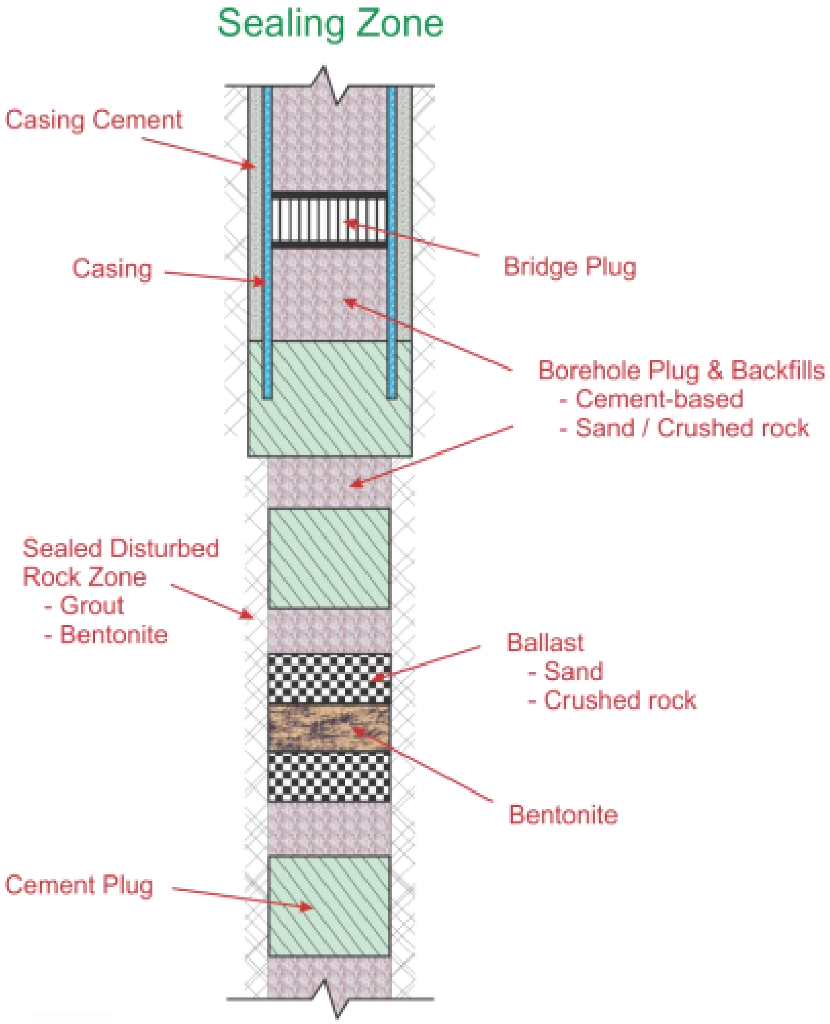
Introduction: Geologic Nuclear Waste Disposal

- Emplacement of waste packages in borehole repository to isolate radioactive materials
- Risk of waste leakage requires significant analysis before approving any project
- Set up and operation of the repository expected to introduce several mechanical, hydrological, chemical and thermal changes in-situ

Surface disposal schematic *Sassani et al. 2019*

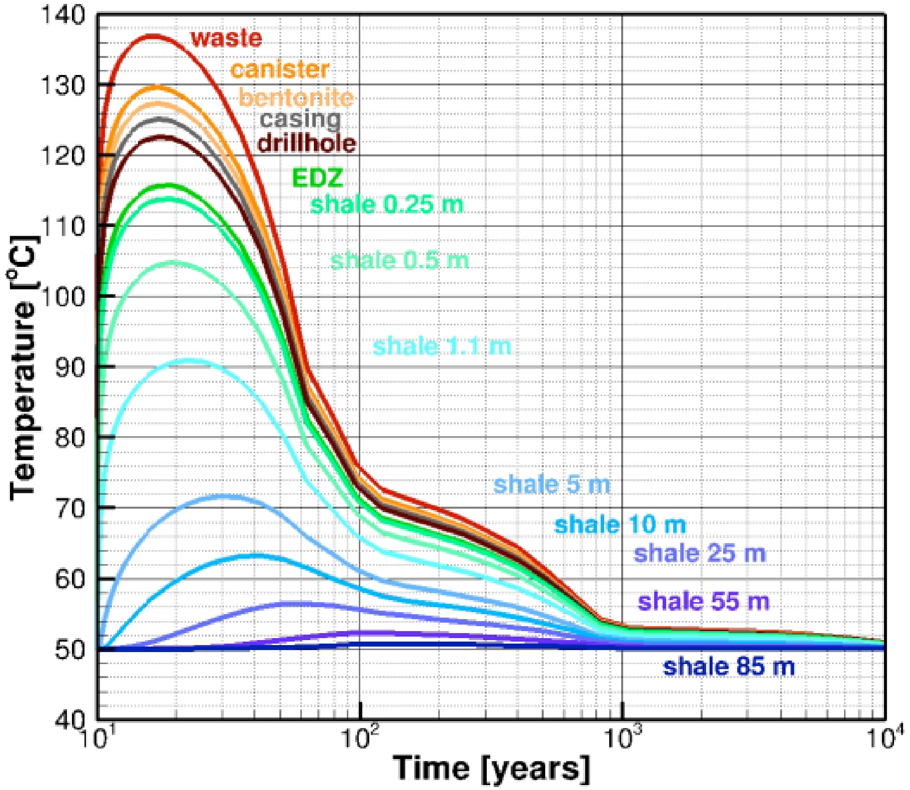




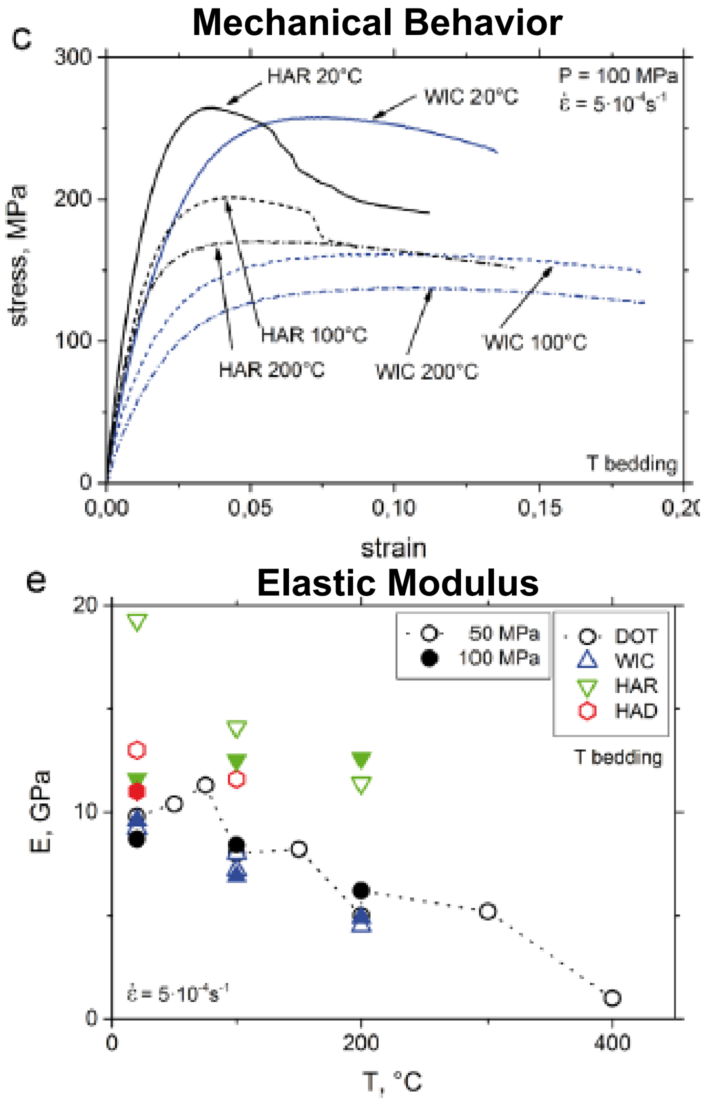
Waste disposal schematic from *Brady et al. 2012*

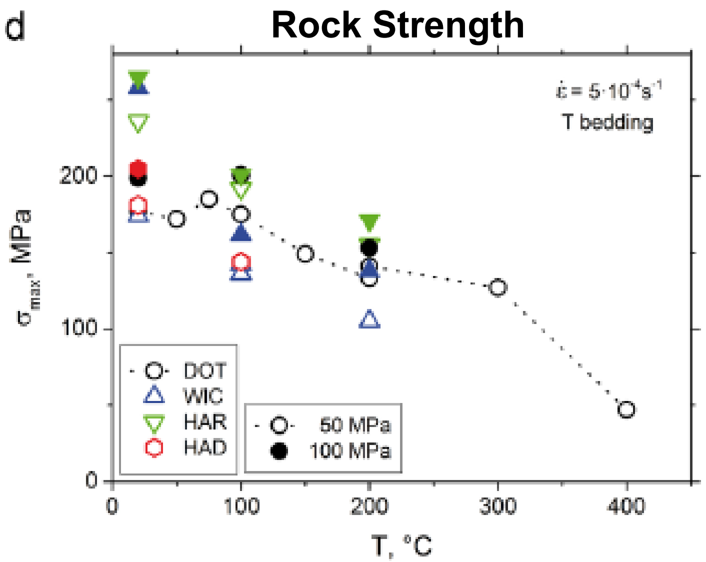
Introduction: Thermal Loading During Operations

Model of temperature with time around waste disposal borehole from *Finsterle et al. 2019*



- Waste emplacement is expected to radiate significant heat into surrounding rock



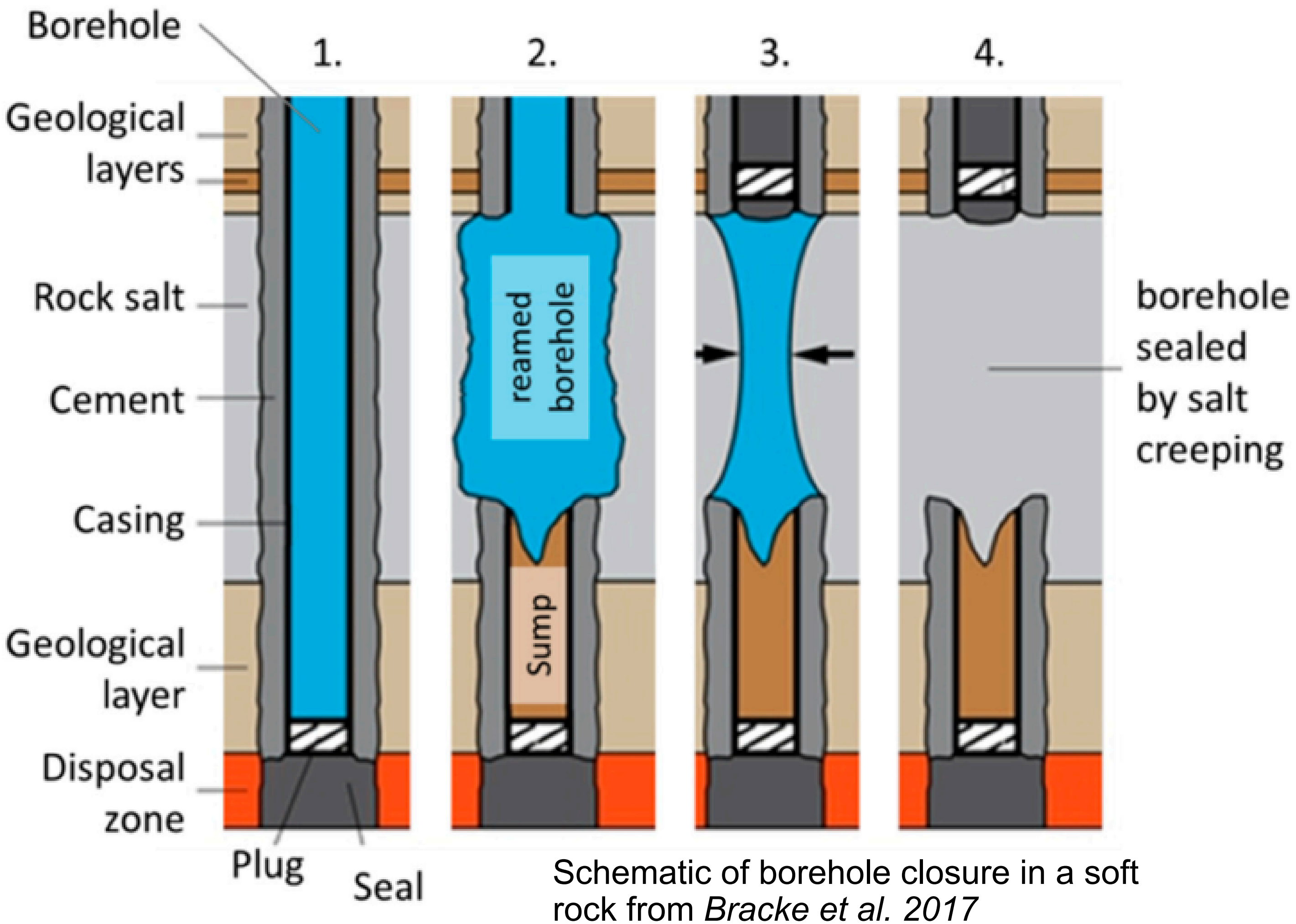


Temperature effect of shale behavior from *Rybacki et al. 2015*

- Significant evidence to show that increasing temperature reduces properties such as rock strength and elastic moduli
- Temperature increases ductility and modifies rock behavior

Introduction: Thermal Loading Good or Bad?

- Thermal loading enhances rock ductility and reduces fracturing
- Thermal load is expected to be relatively small, but for soft rock (e.g., salt, carbonates, shale) the effect is expected to be large
- Increased temperature could reduce risk of permeability modification by fracturing and more easily isolate borehole



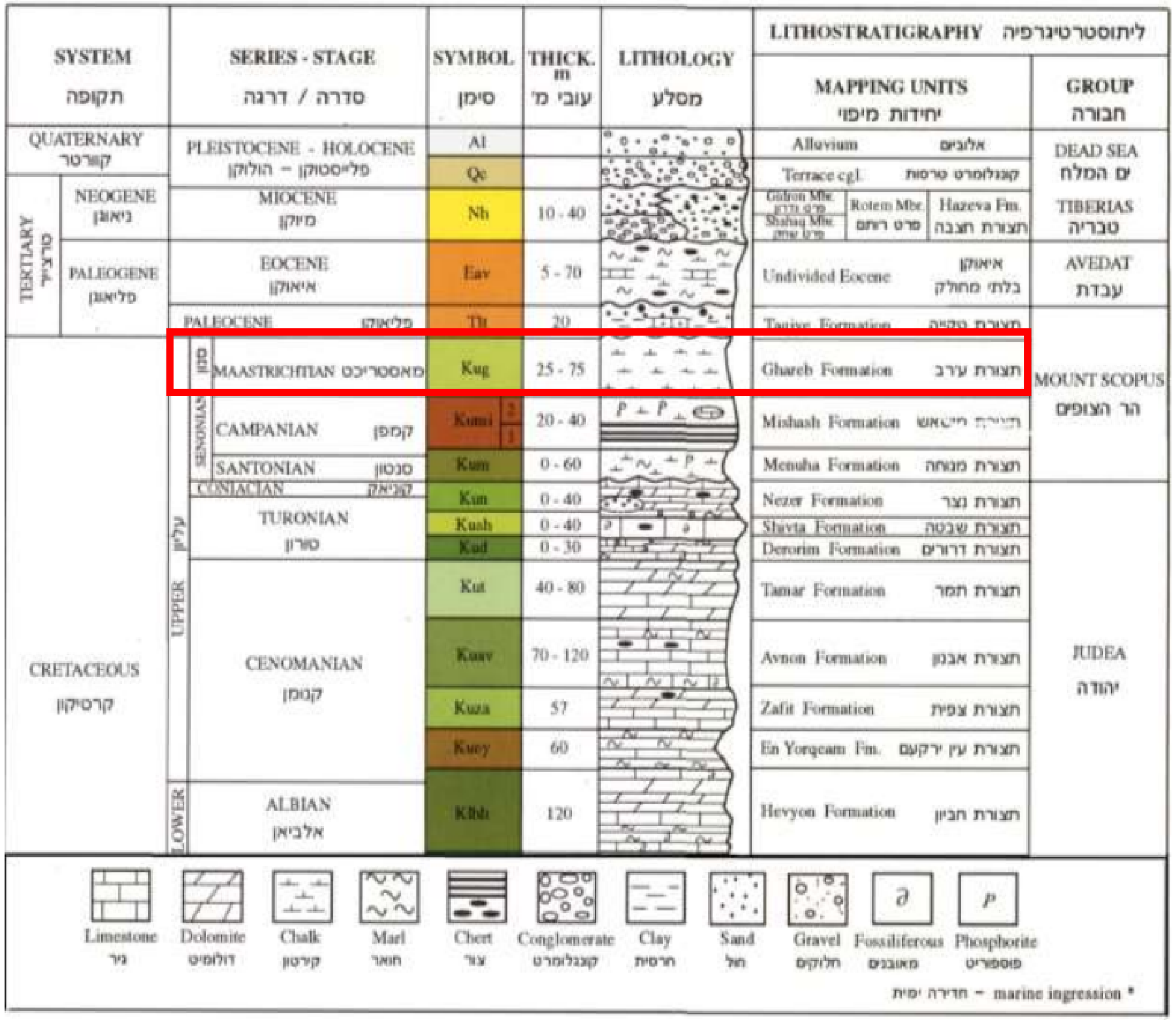
Schematic of borehole closure in a soft rock from *Bracke et al. 2017*

How much will an increasing temperature in a soft rock considered for hosting nuclear waste alter deformation?

Materials: **Ghareb Formation**

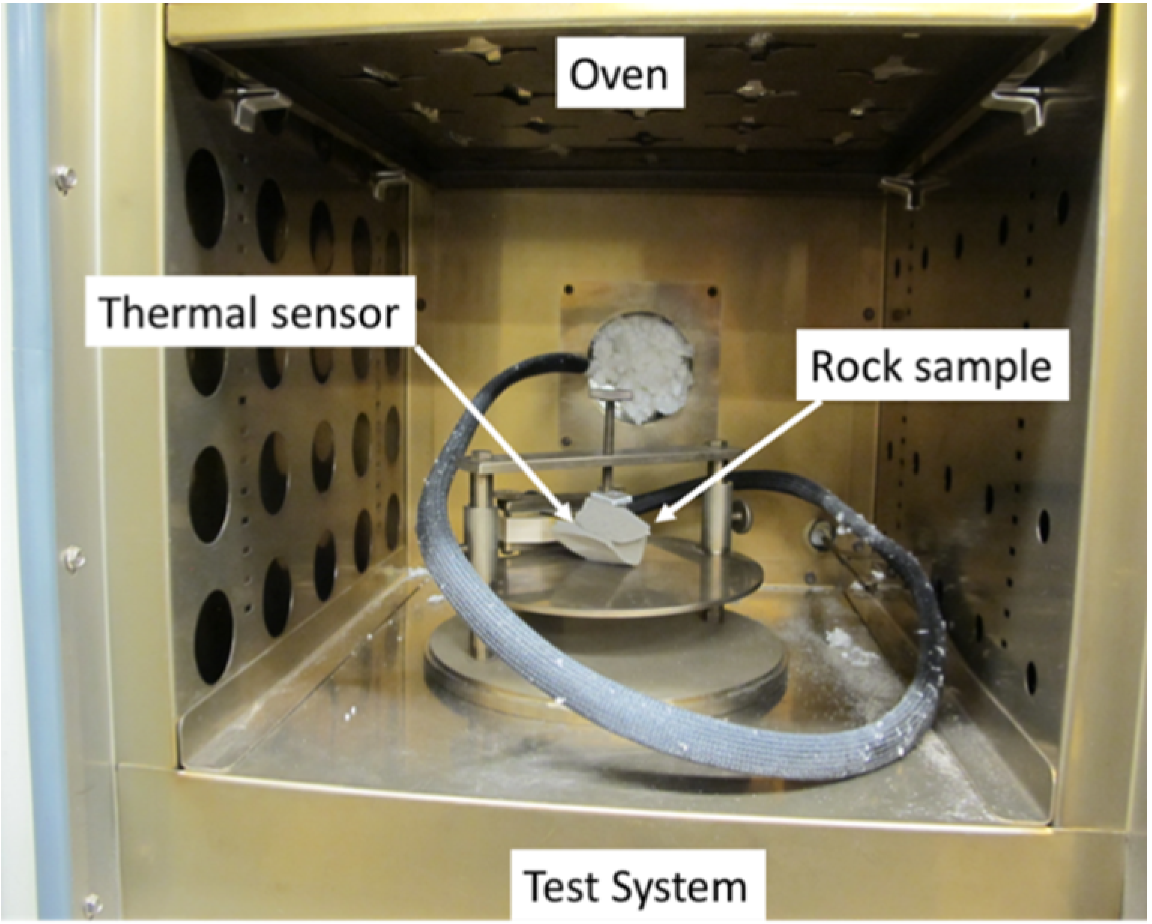
- Ghareb formation in southern Israel main host rock
- Porous chalky marl
- High kerogen and sulfur content
- Shallow depth in target region (150-300 m)

Quarried block from formation used in research



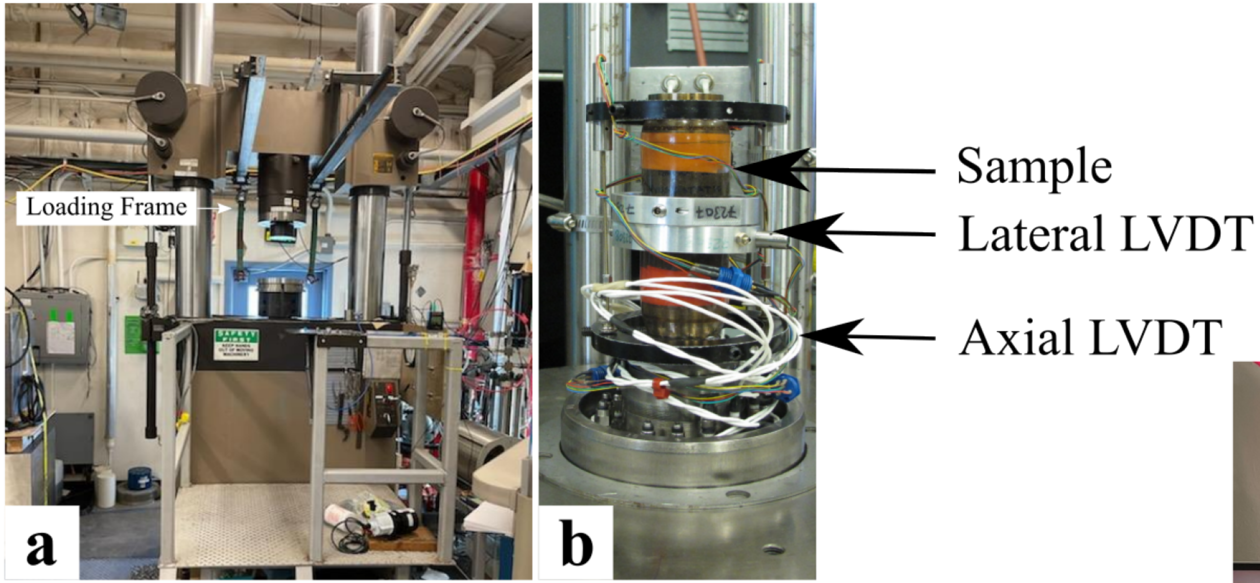
Stratigraphic column of Yamin plain where host rock is located from *Freeze et al. 2020*

Methods: Thermal Property Measurements

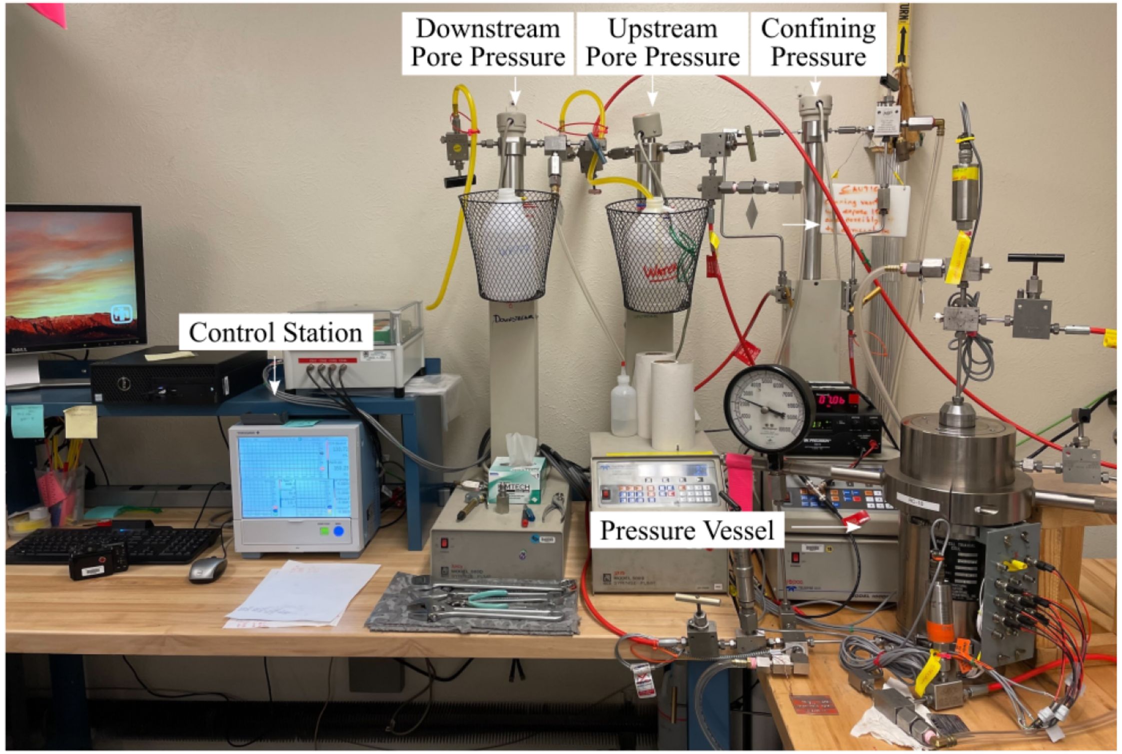


- Hot disk analyzer measures:
  - Thermal conductivity (W/mK)
  - Thermal diffusivity (mm^2/s)
  - Specific heat capacity (MJ/m^3*K)
- Samples from two separate quarried blocks (Set #1 and Set #2) tested dry from 40 to 275 ˚C
- Sample from each block was tested water-saturated to measure thermal properties and water loss with increasing temperature

Methods: **Mechanical Tests**



- 1 hydrostatic creep test at 8 MPa effective pressure and temperatures of:
  - 20, 40, 60, 80, 100 ˚C

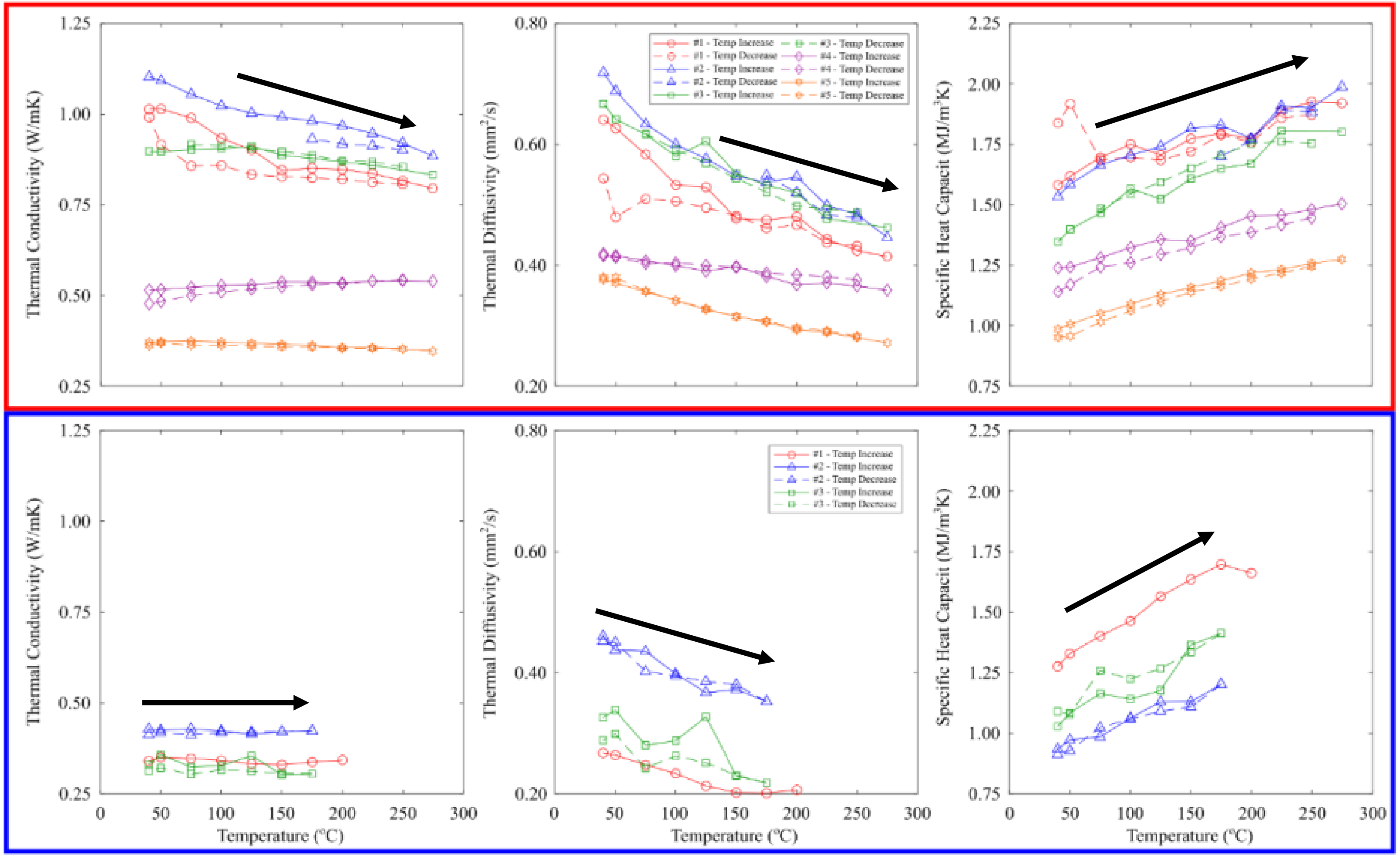


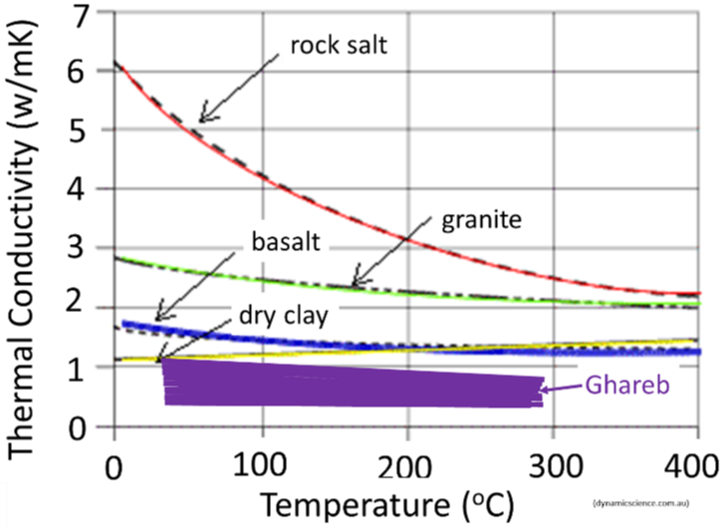
- 2 triaxial tests with different loading rates measuring creep at:
  - 0, 5, 10, 15 MPa differential stress
  - 100 ˚C and 15 MPa differential stress

Results: Thermal Properties of Host Rock

Set #1

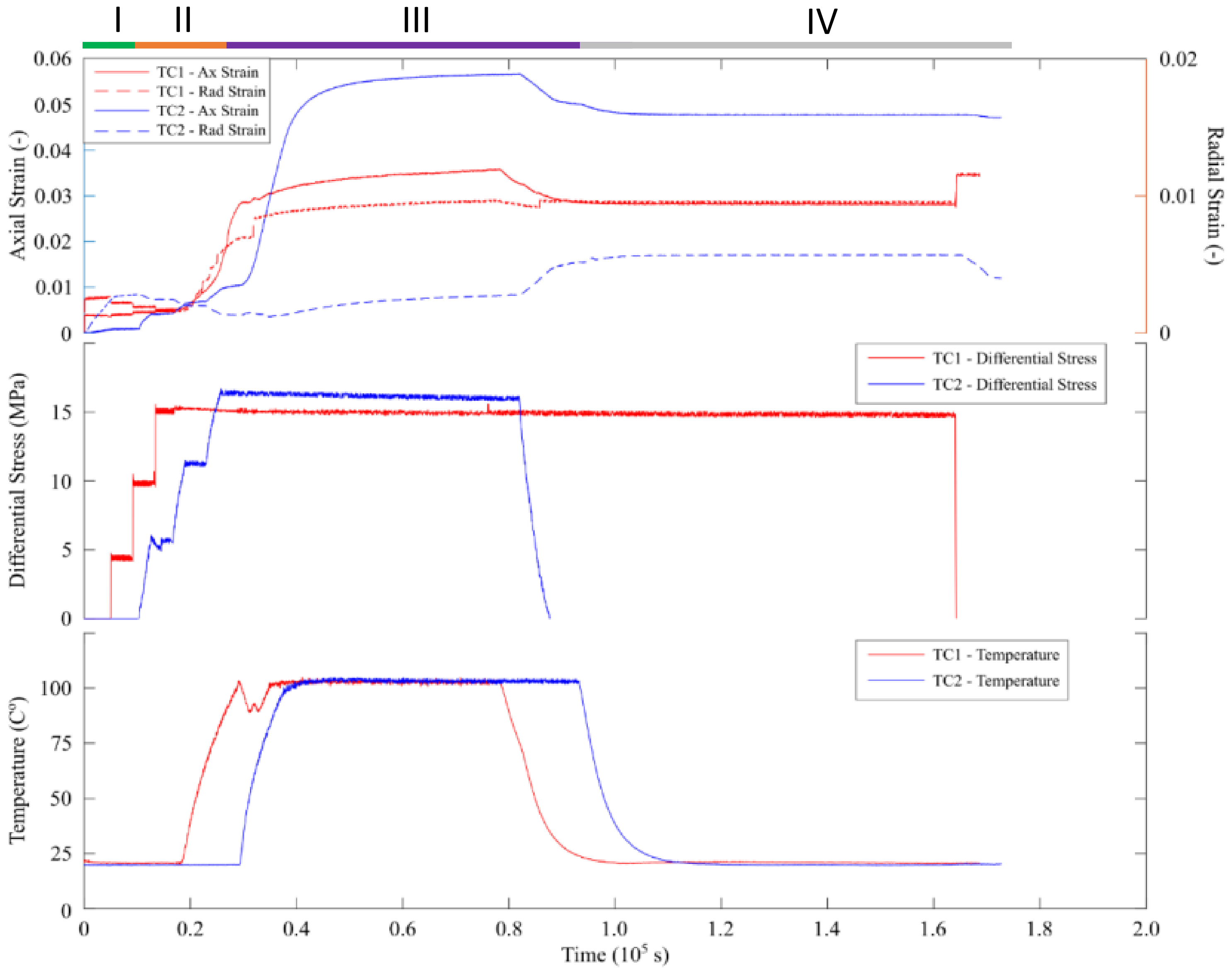
Set #2





- Low conductivity and diffusivity implies heat will be slow to transfer from waste to formation
- High clay/mud content may reduce values below expected for chalk (~1.5-2.5 W/m*K) or marl (~2.1-2.8 W/m*K)

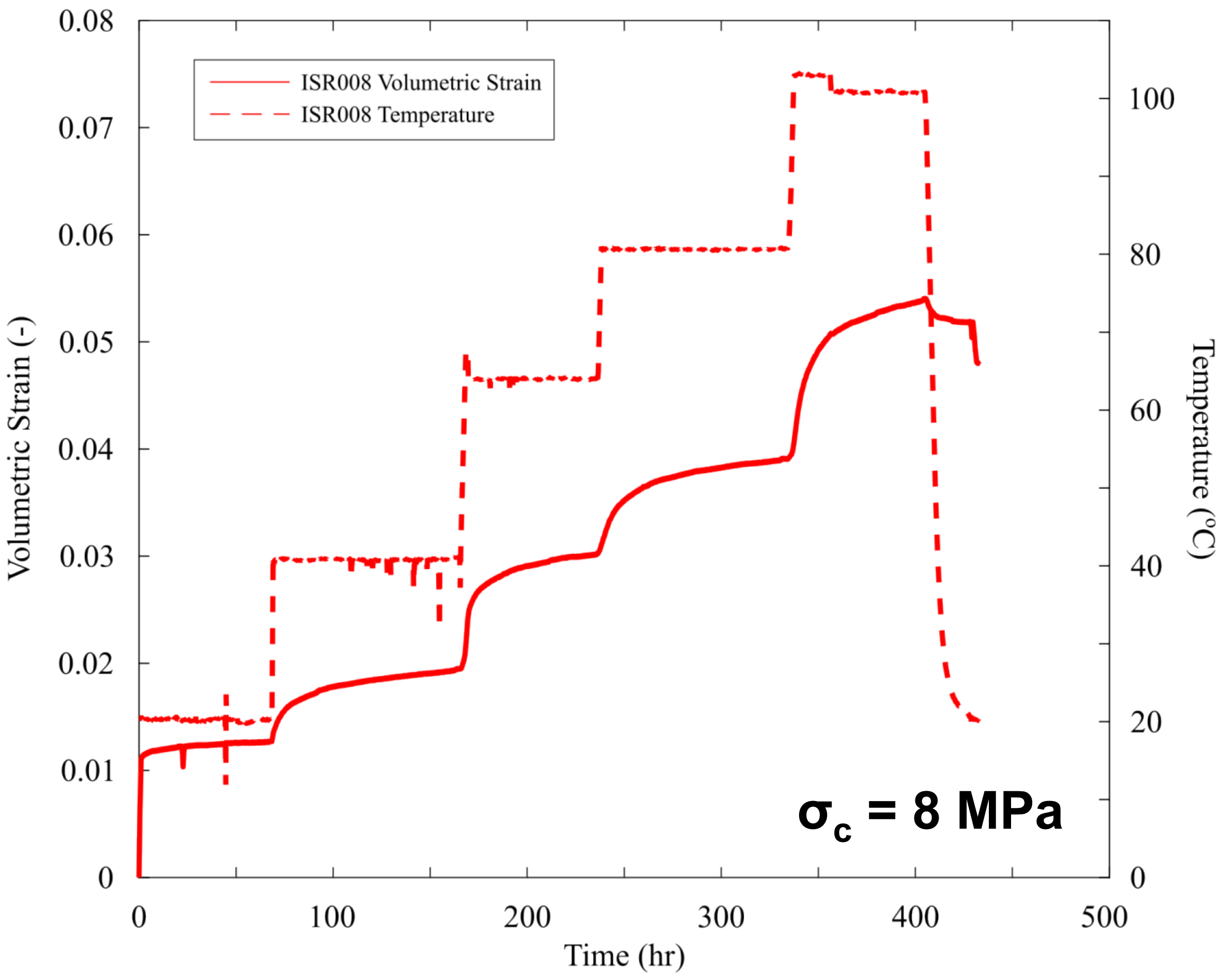
Results: Triaxial Creep Tests



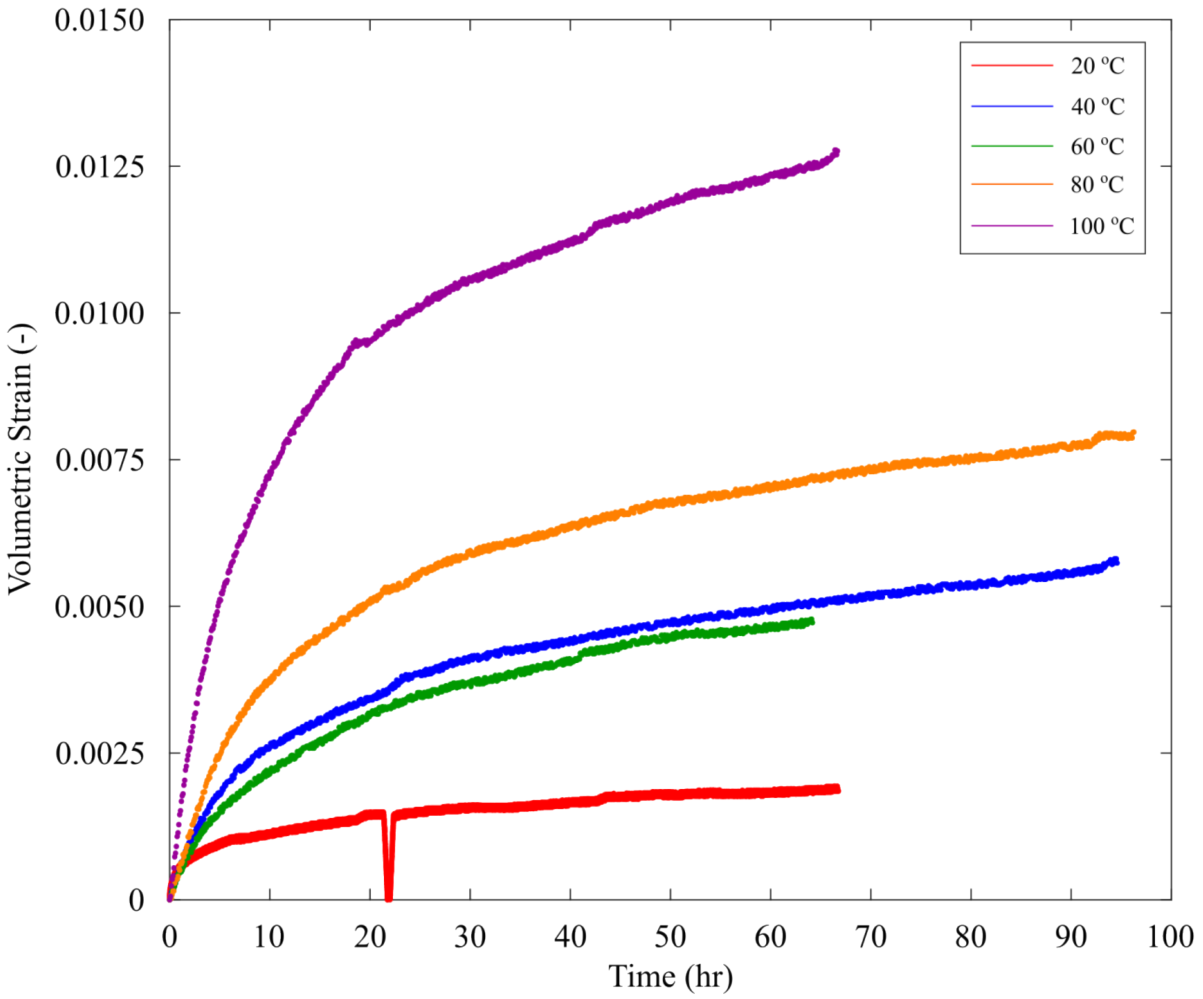
- I: Confining Pressure Increase
- II: Differential Stress Loading and Holds
- III: Temperature Increase and Holds
- IV: Differential Stress Unloading

Results: Hydrostatic Creep Test with Increasing Temperature

Time vs Volumetric Strain and Temperature

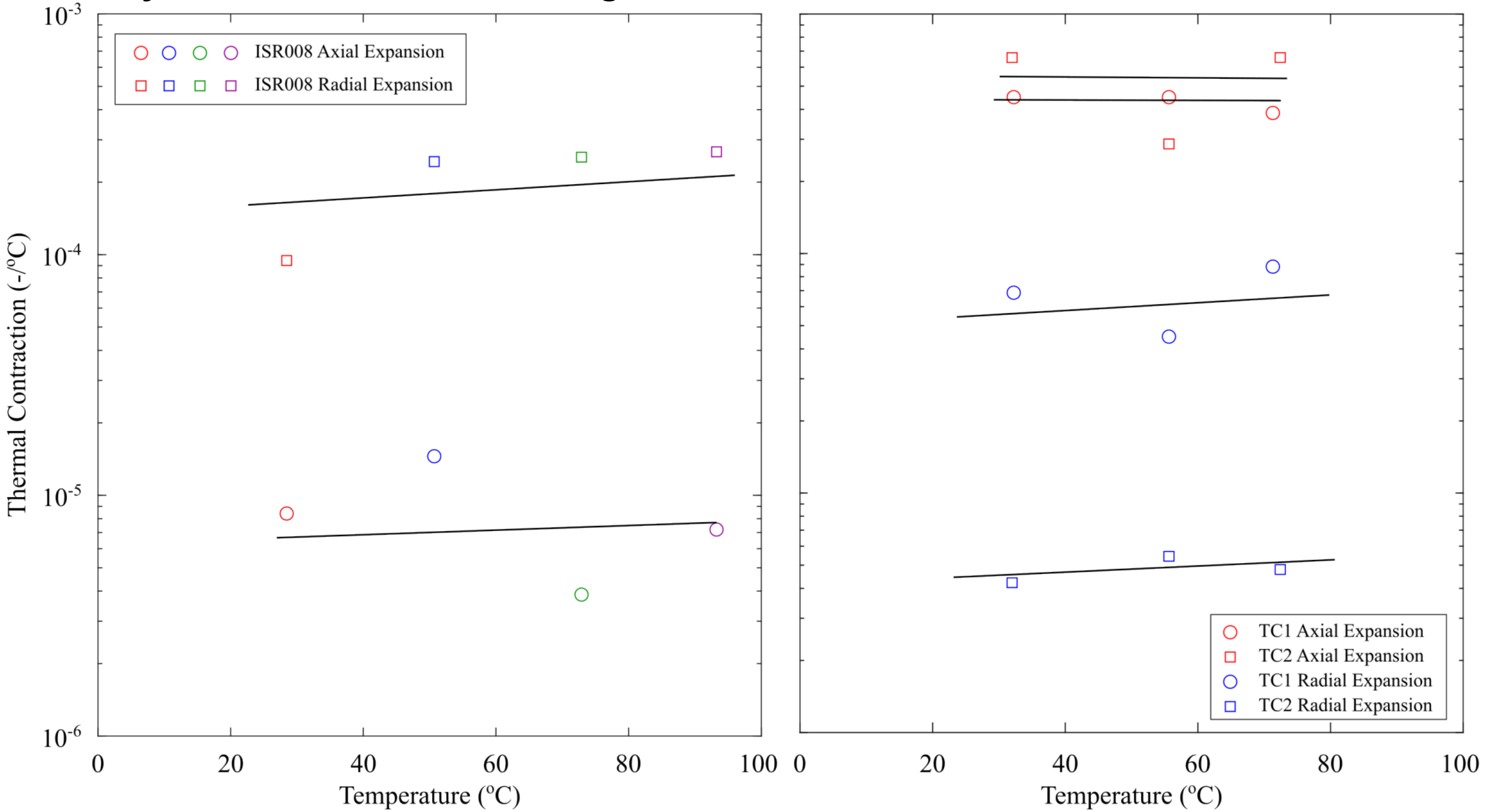


Normalized Volumetric Strain at Different Temperatures



Discussion: Thermal Contraction Under Stress

Hydrostatic = 8 MPa Confining Pressure | **Triaxial = 15 MPa Differential Stress**

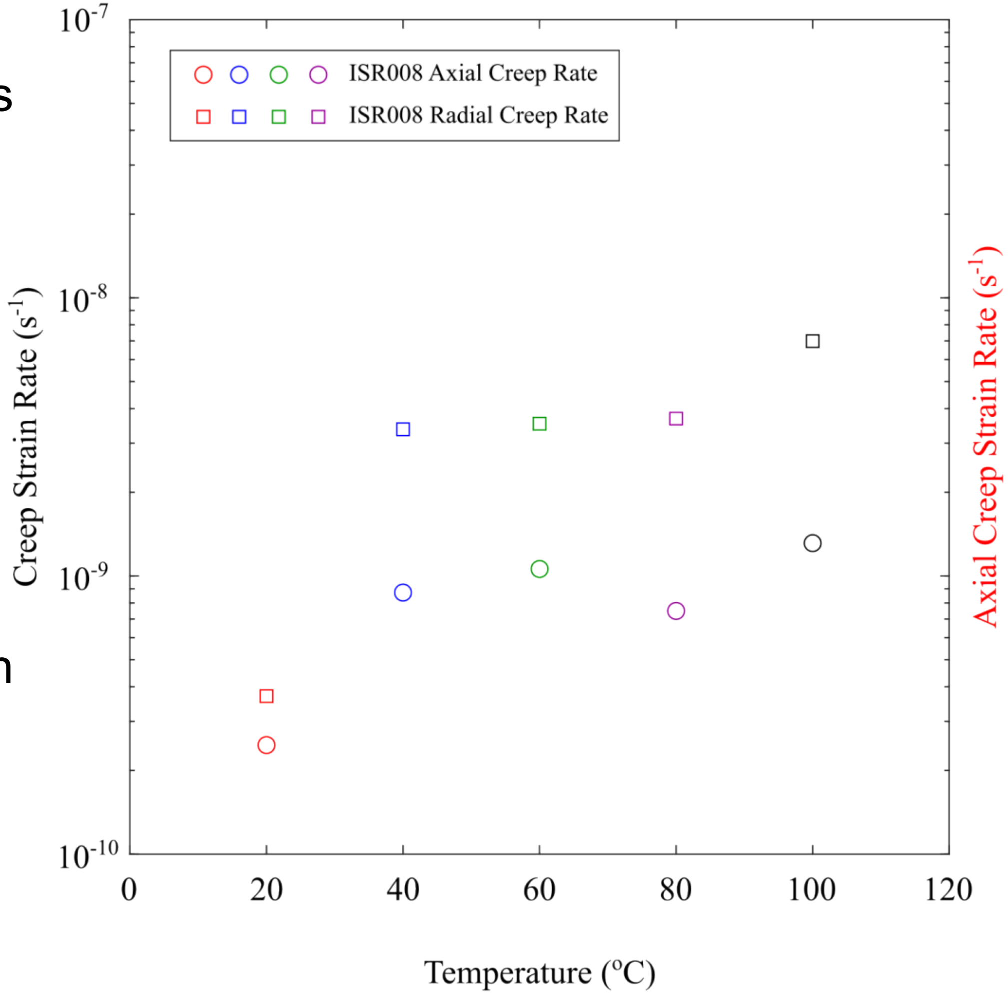


- Compaction strain of axial and radial strain when temperature is increased
- Slight increase in contraction with increasing temperature
- Axial contraction is greater under differential stress

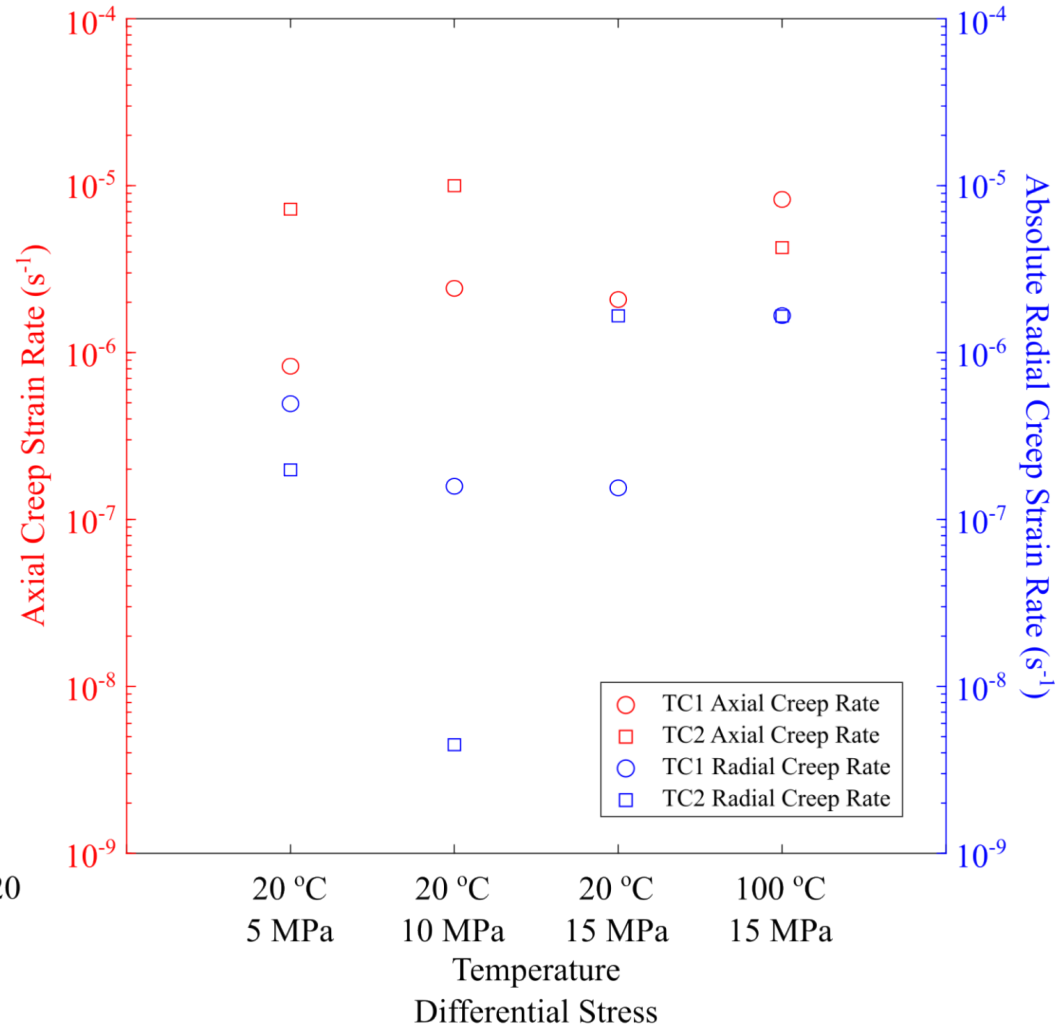
Discussion: Thermal Effect Under Creep Conditions

- Creep strain rates increase with temperature
- Under differential stress conditions, radial strain rate is negative at 20 ˚C but positive at 100 ˚C
- Strain rates are not affected much by increases in differential stress

Hydrostatic = 8 MPa Confining Pressure



Triaxial = 15 MPa Differential Stress



Conclusions

- Low thermal properties indicate heat will be slow to diffuse from waste into formation and away from borehole
- Temperature increase generates greater strain than stress increases
- Rate of thermal contraction is controlled by stress field applied
- High creep rate and thermal properties suggest that deformation around borehole will be heightened by thermal loading
- Catastrophic failure or fracture propagation are unlikely due to compaction strain dominating over dilatant strain (i.e., fracturing nucleation and extension)

Acknowledgements

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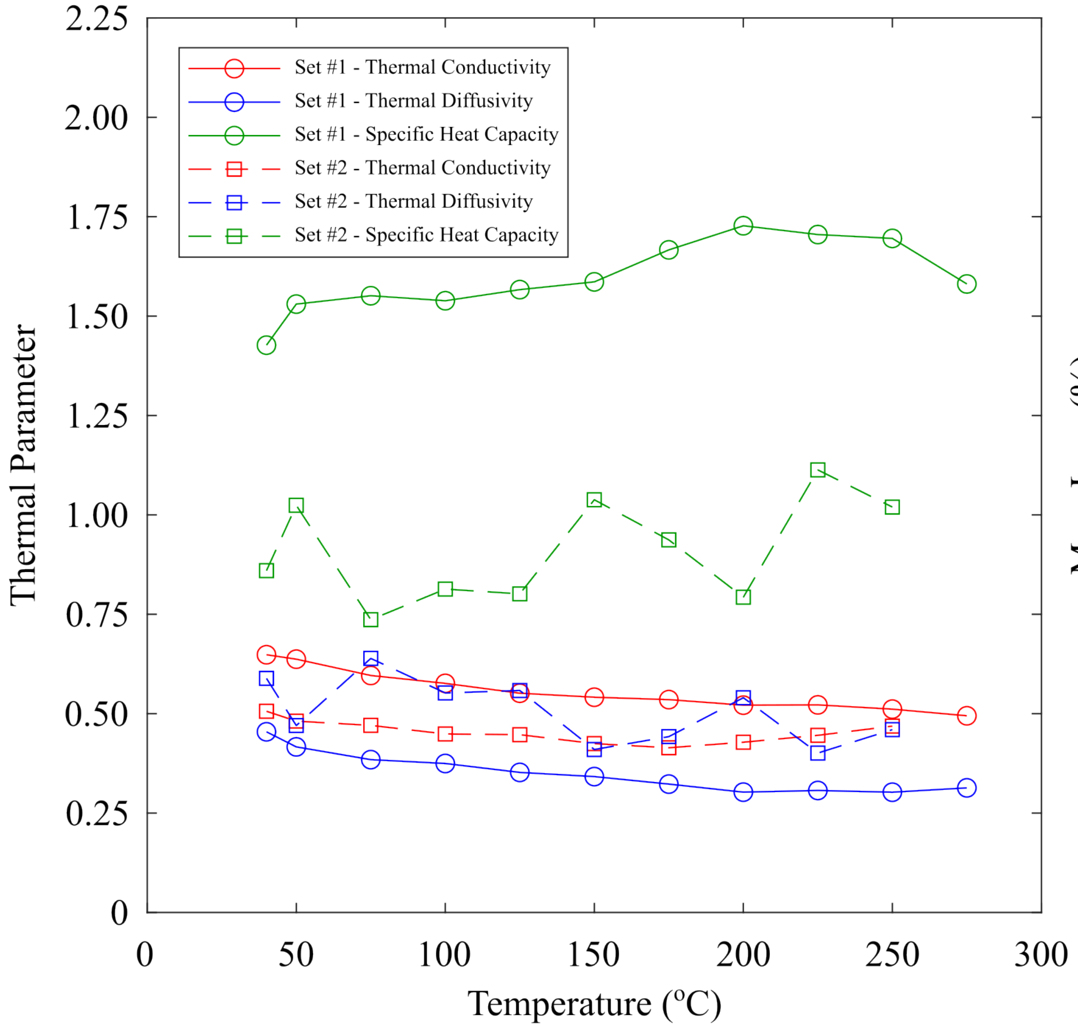
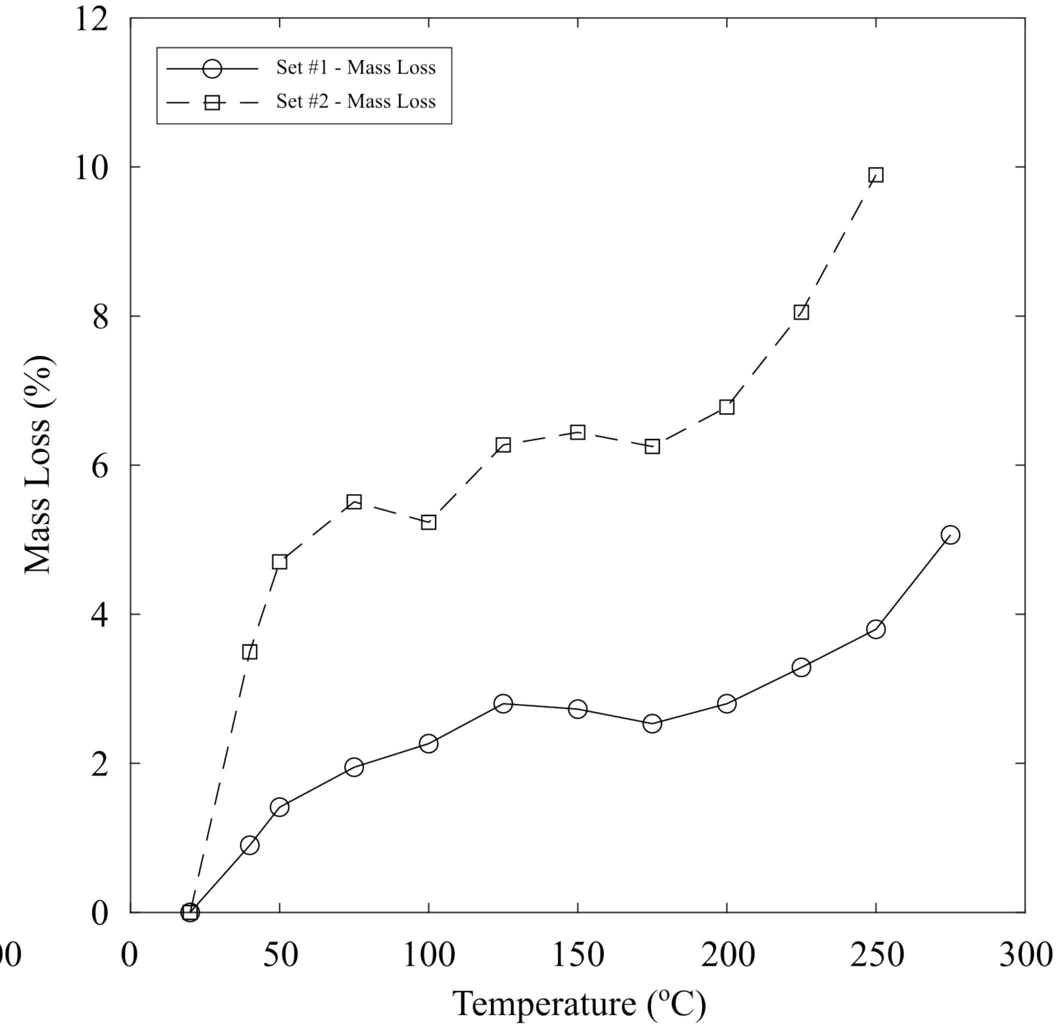
Results: Mass Loss and Saturation Effect

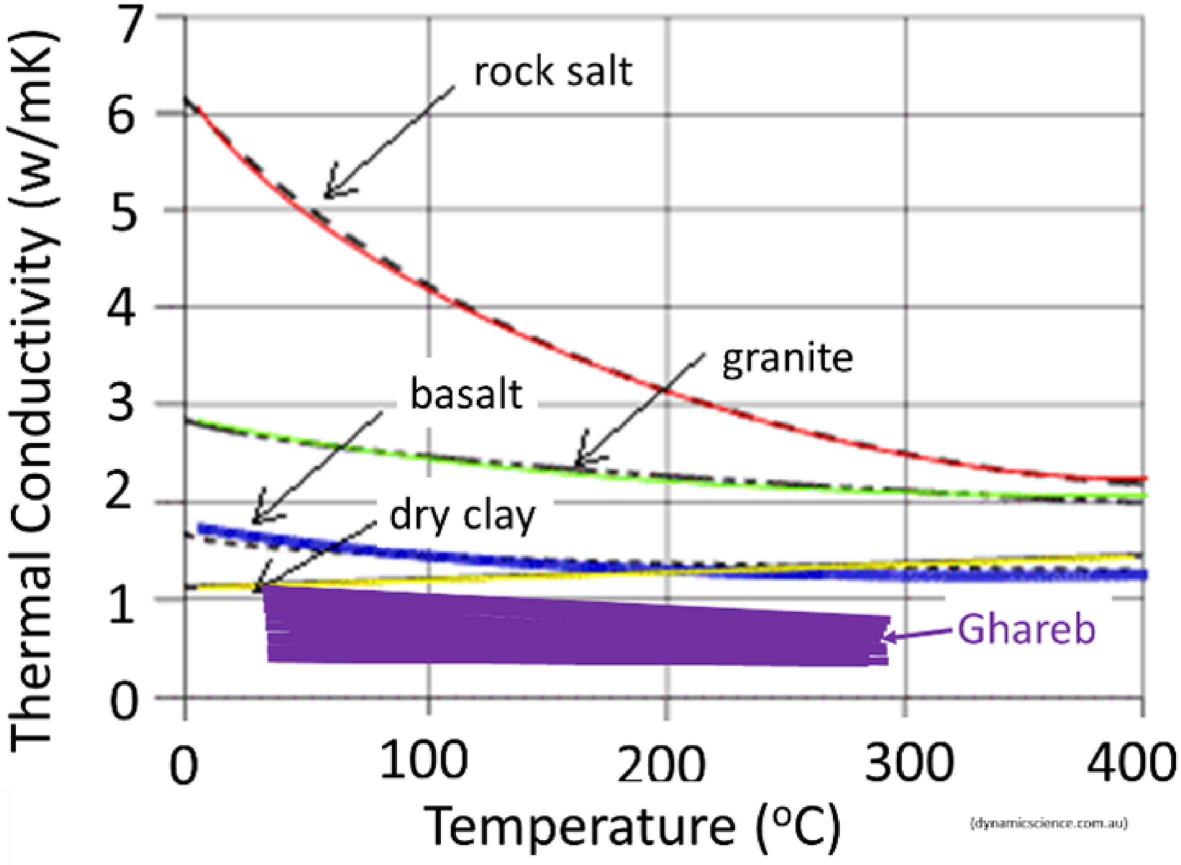




- Conductivity and diffusivity similar to dry tests with lower values, specific heat similar but changes little
- Significant mass loss occurs from 20-75 ˚C and 200-275 ˚C

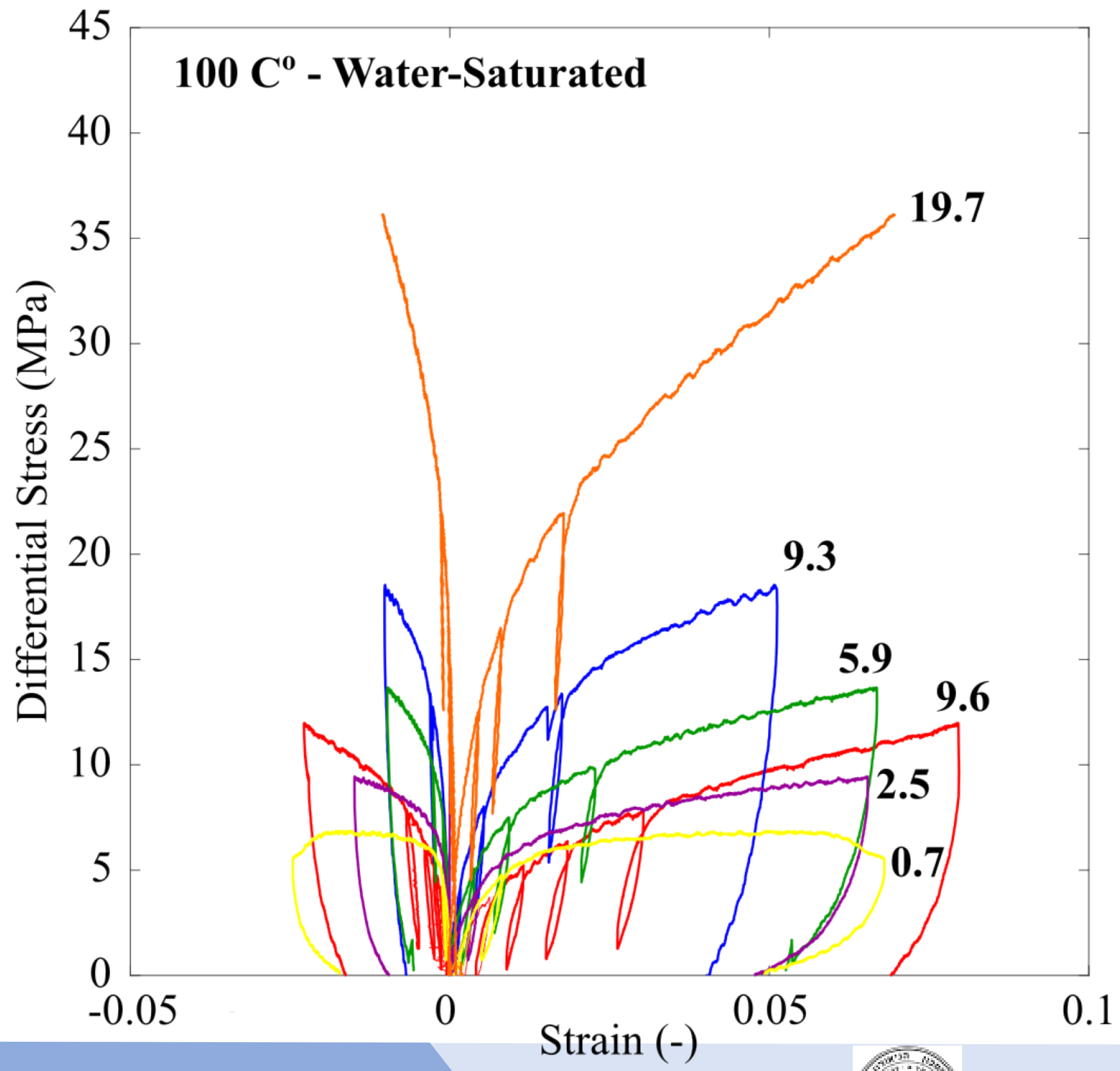
Discussion: Thermal Property Comparison

- Low conductivity and diffusivity implies heat will be slow to transfer from waste to formation
- High clay/mud content may reduce values below expected for chalk (~1.5-2.5 W/m*K) or marl (~2.1-2.8 W/m*K)



Thermal conductivity of several rock types compared with Ghareb tests modified from *Bauer et al. 2021*

Results: Triaxial Loading



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