MIT EARTH RESOURCES LABORATORY
ANNUAL FOUNDING MEMBERS MEETING 2020

# Time-dependent Brittle Deformation in Basalt


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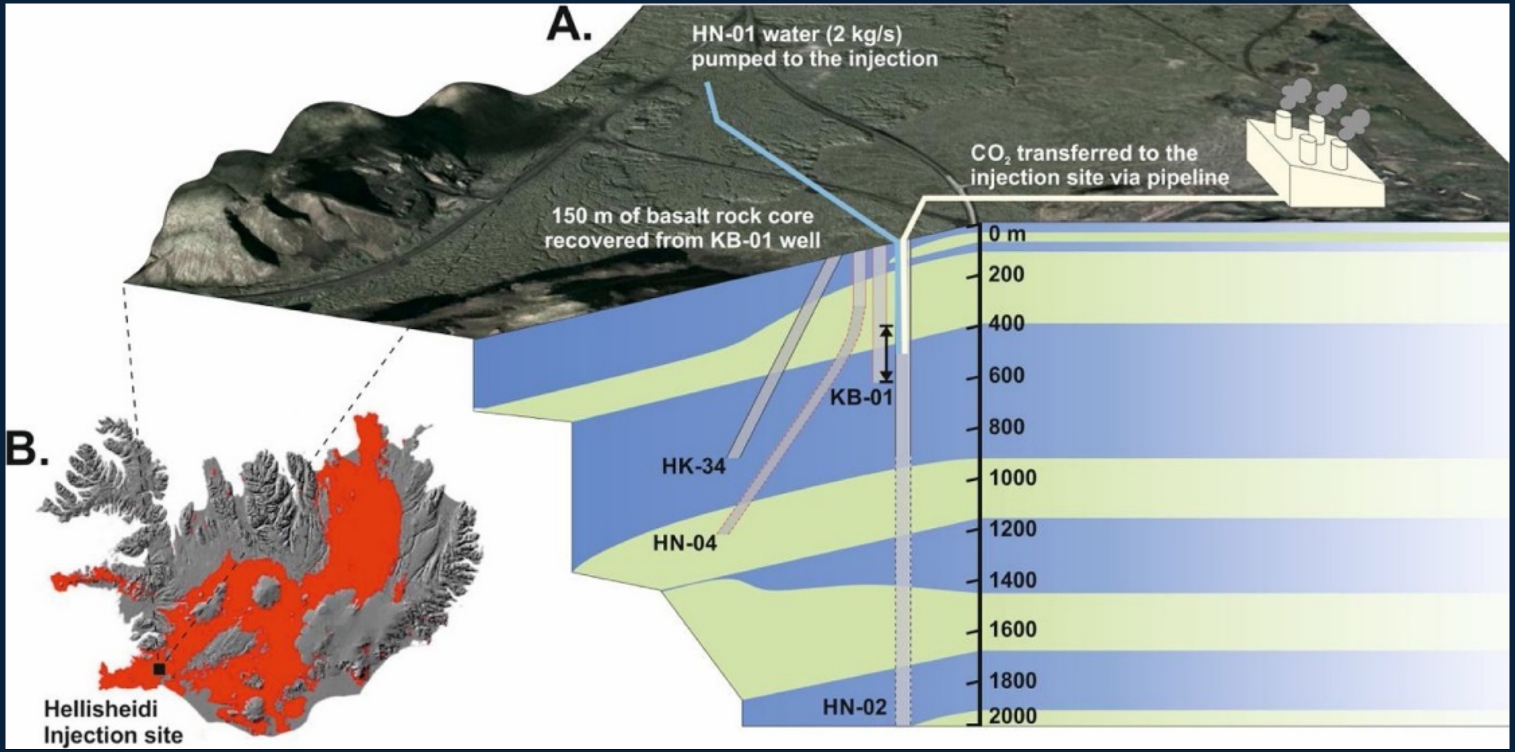
*In collaboration with Matej Pec, Hamed Ghaffari, Ulrich Mok, Lubna AlBarghouty*

# Geological $CO_2$ Storage Using Basalts

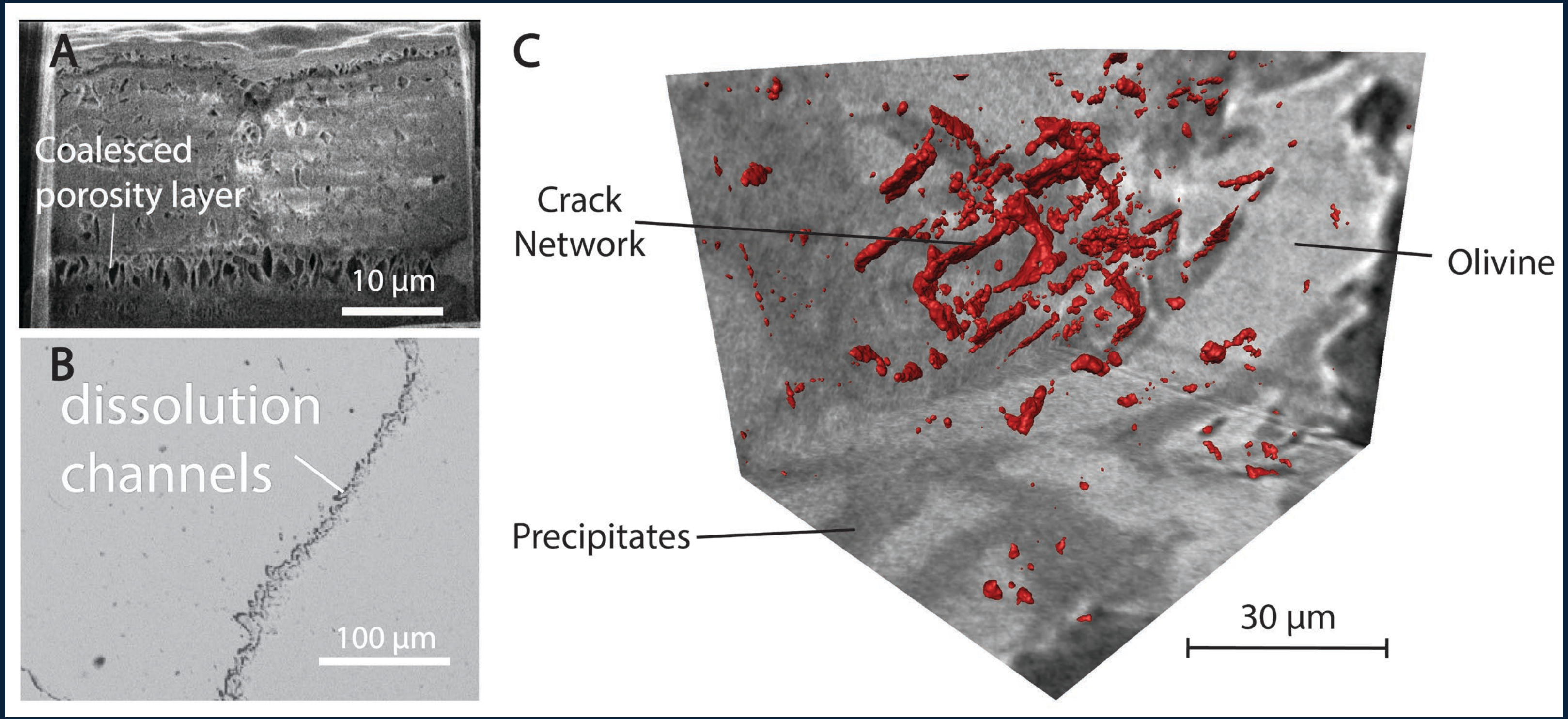
- Geological $CO_2$ Storage (GCS) is proposed as a permanent solution to the increasing $CO_2$ concentration in the atmosphere
- $CO_2$ is converted to solid carbonates through reaction with Mg, Ca rich minerals
- Basaltic rocks are considered as reservoirs due to their widespread occurrence and high Mg, Ca content
- Pilot site in Iceland has injected 23,200 metric tons of $CO_2$ by 2017, with carbon storage efficiency of 72 ± 5% (von Strandmann et al., 2019)




Callow et al. (2018)

# Rock-fluid Interaction

- The deformation of rocks can be affected by the interaction between rock and fluid
- Mechanically, fluid can alter the stress condition
- Fluids also react with rocks, changing the bulk composition and altering their pore structure
- What is the influence of $CO_2$-rich fluids on the strength and permeability of basaltic rocks?

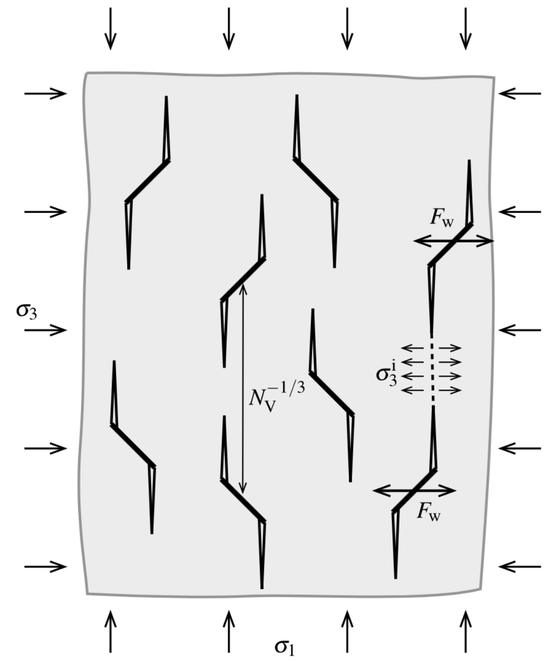



Lisabeth et al. (2017)

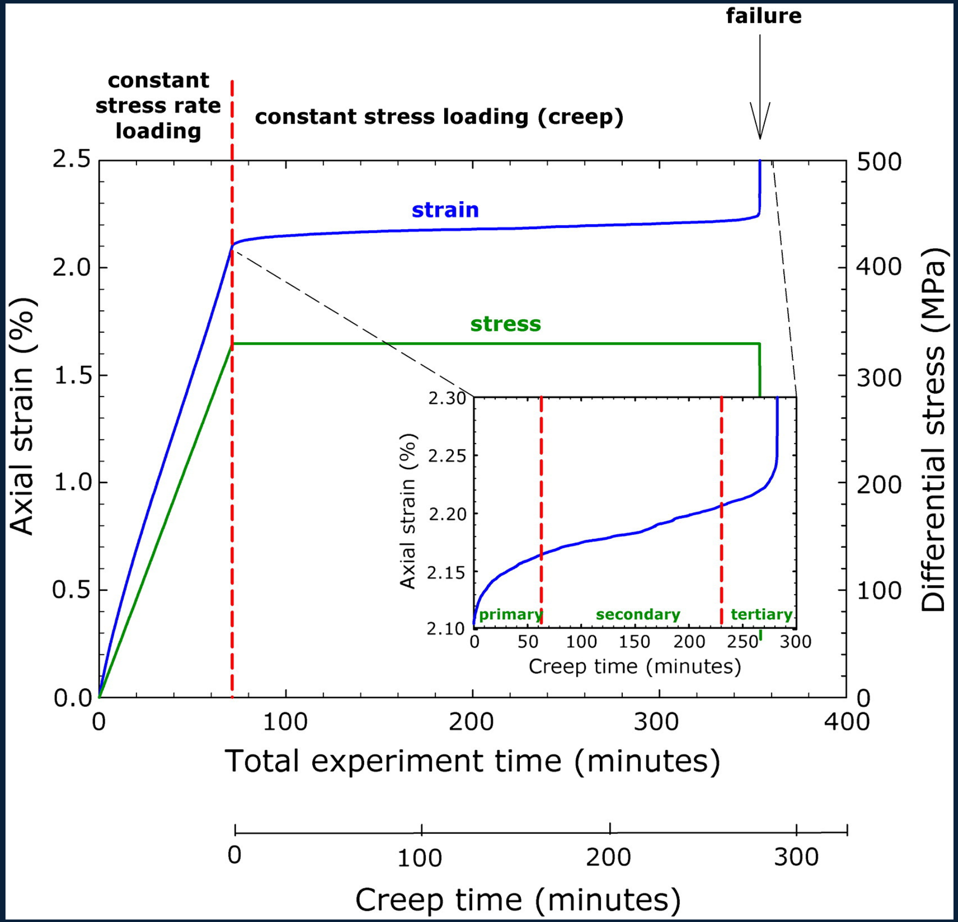
Xing et al. (2018)

# Brittle Creep Deformation

- Rocks can fail at constant applied stresses below their short-term strength due to creep
- Flaws in rocks are subcritically stressed and propagate slowly due to stress corrosion (a chemical weakening process) at crack tips (e.g. Hadizadeh and Law, 1991)
- Critical fracture then occurs after some time delay when the cracks coalesce and reach a critical length
- Fluid-rock interactions can affect the crack growth rate




Brantut et al. (2012)




Heap et al. (2011)

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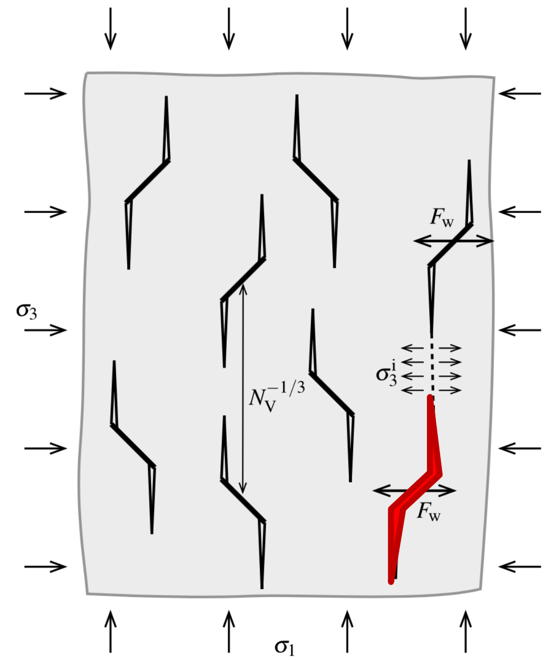


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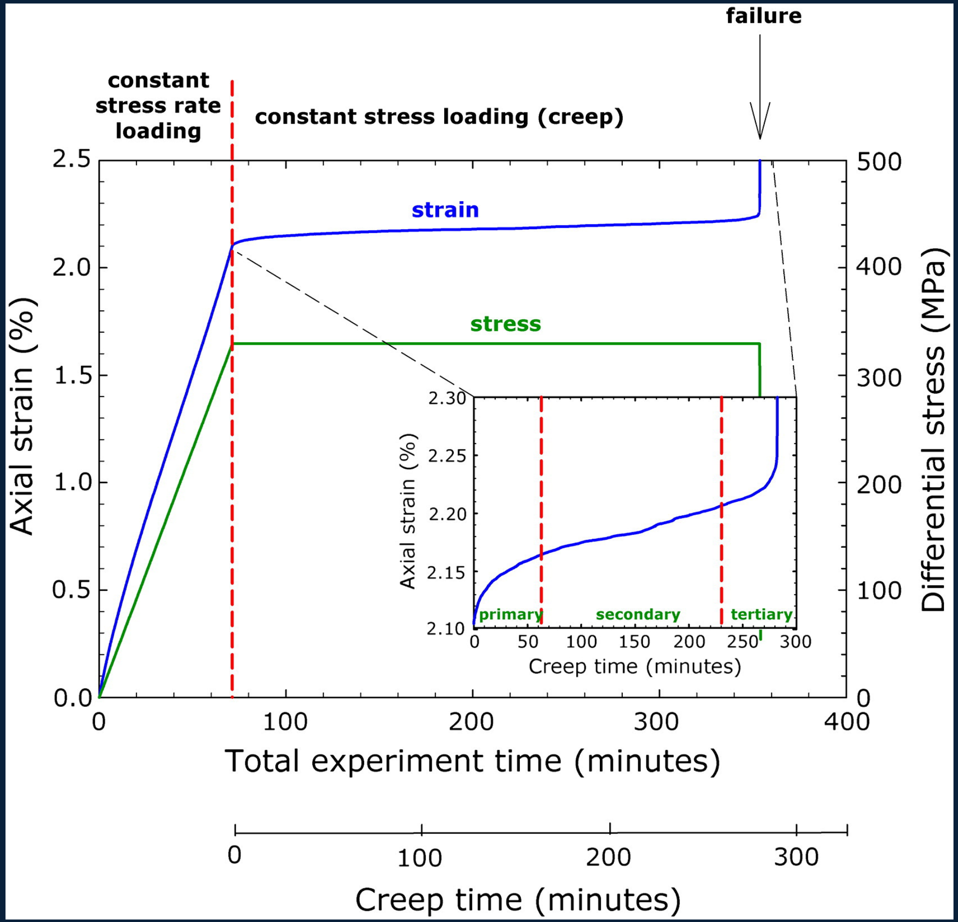


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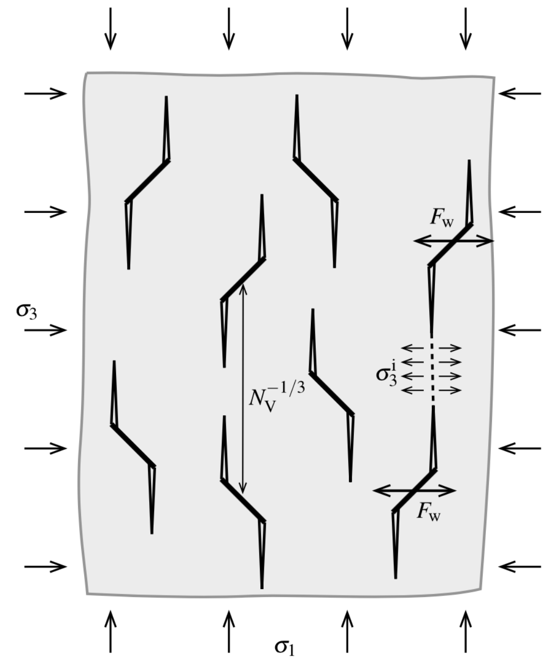


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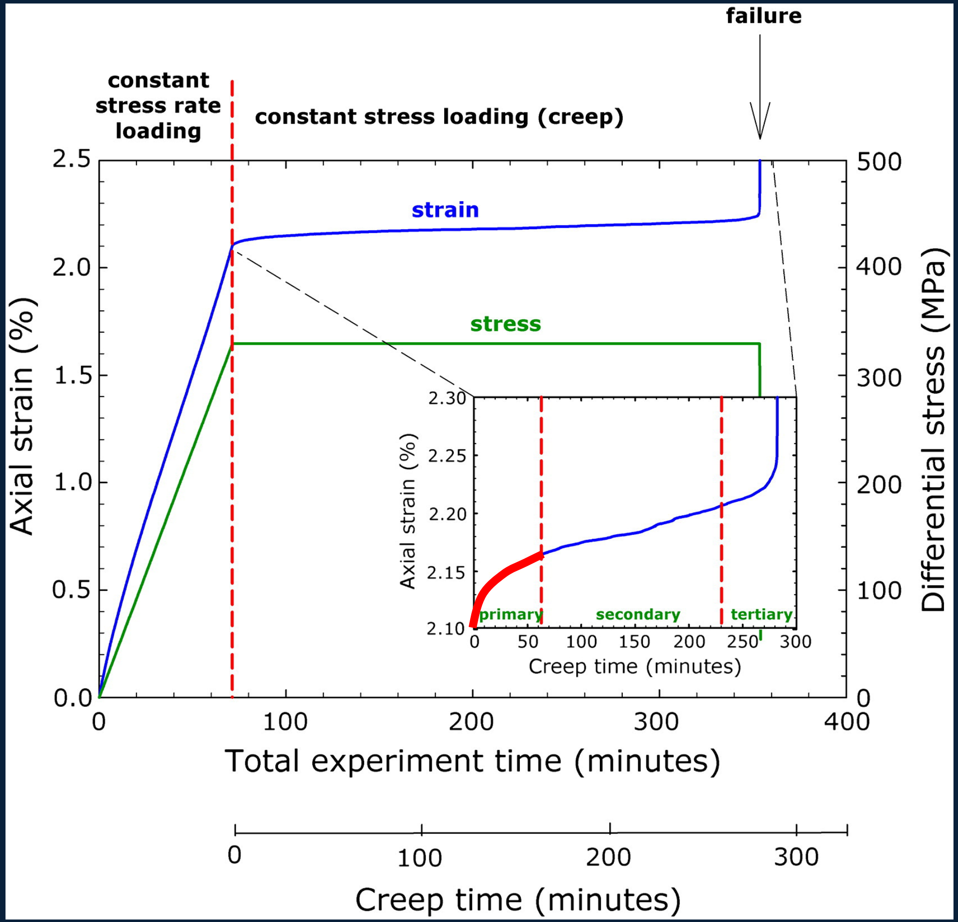


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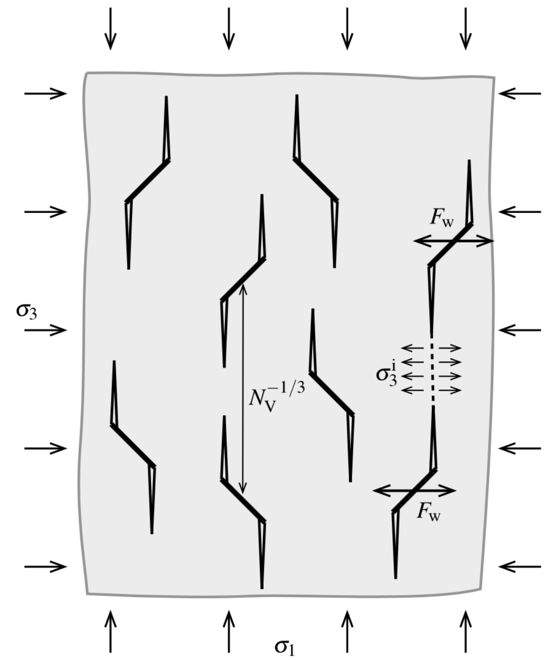


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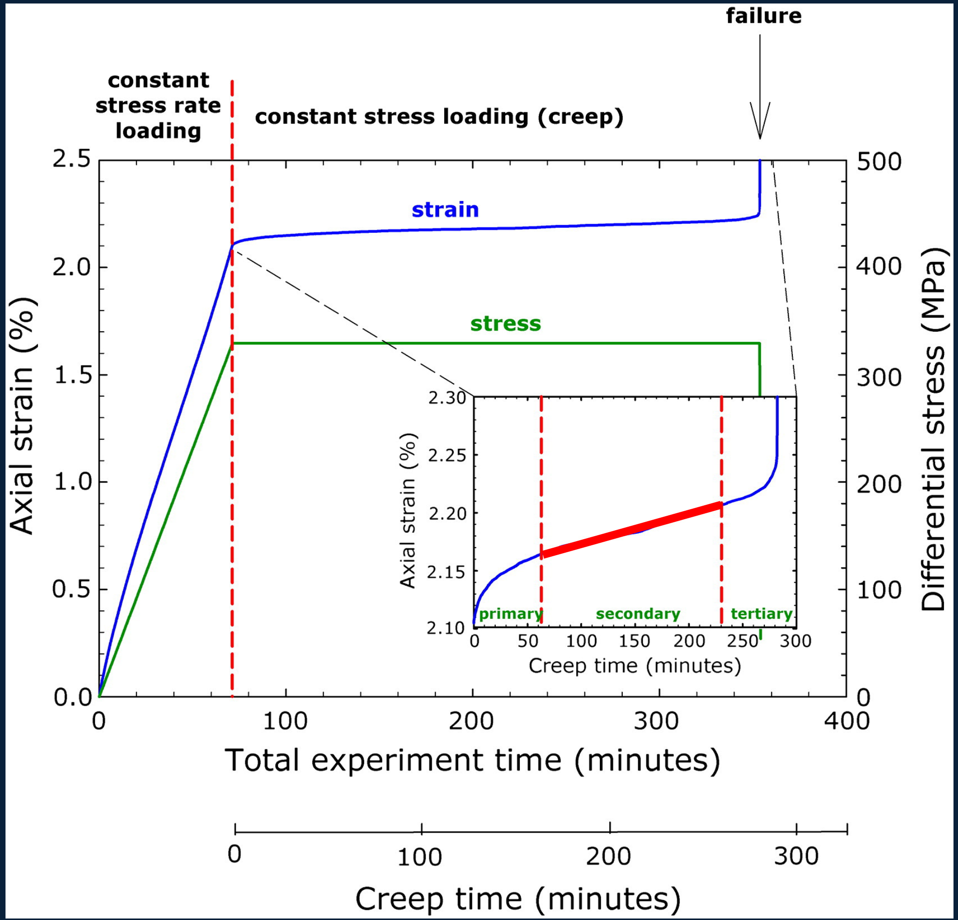


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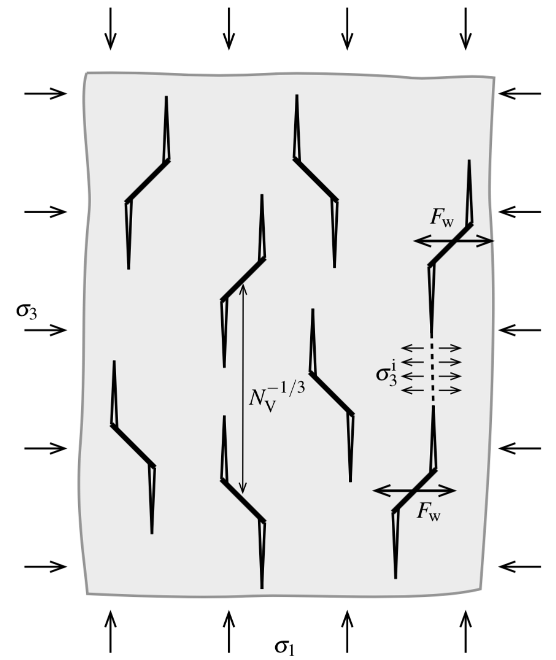


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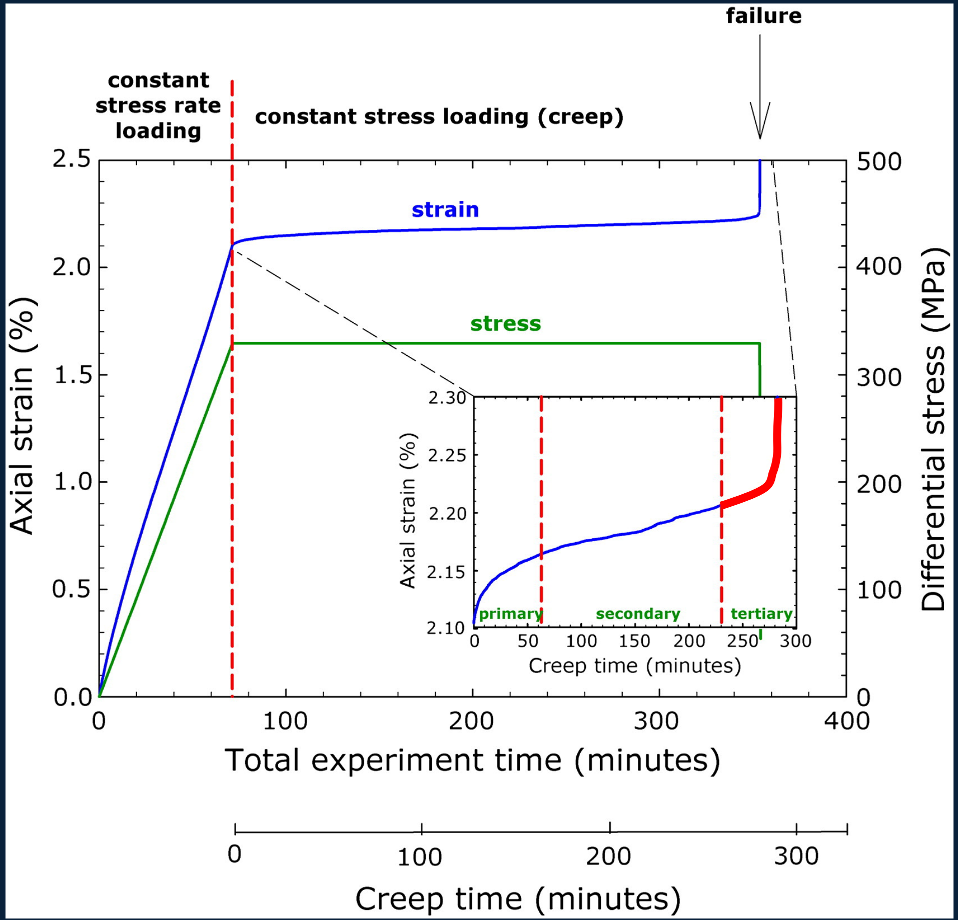


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# Experiment Design

- **Objectives (Multiphysics Characterization):**
  - *Failure strength*
  - *Creep rate*
  - *AE signatures*
  - *Vp & Vs evolution*
  - *Poro-perm evolution*
  - *Size/scale effect*
  - *Fluid composition* evolution
- **Sample Diameter:**
  - *3 inches in height*
  - *1.5 inches in diameter*
- **Dry & saturated (Water/$CO_2$) experiments**
- **All at reservoir P-T conditions**

  *(Peff= 50 MPa, T= 23˚~80˚C)*
- **Sample deformed using AutoLab-3000 Apparatus in the Rock Deformation Lab (54-714 EAPS, MIT)**


**Basalt from CarbFix site, Iceland**

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Future work

- **All at reservoir P-T conditions**

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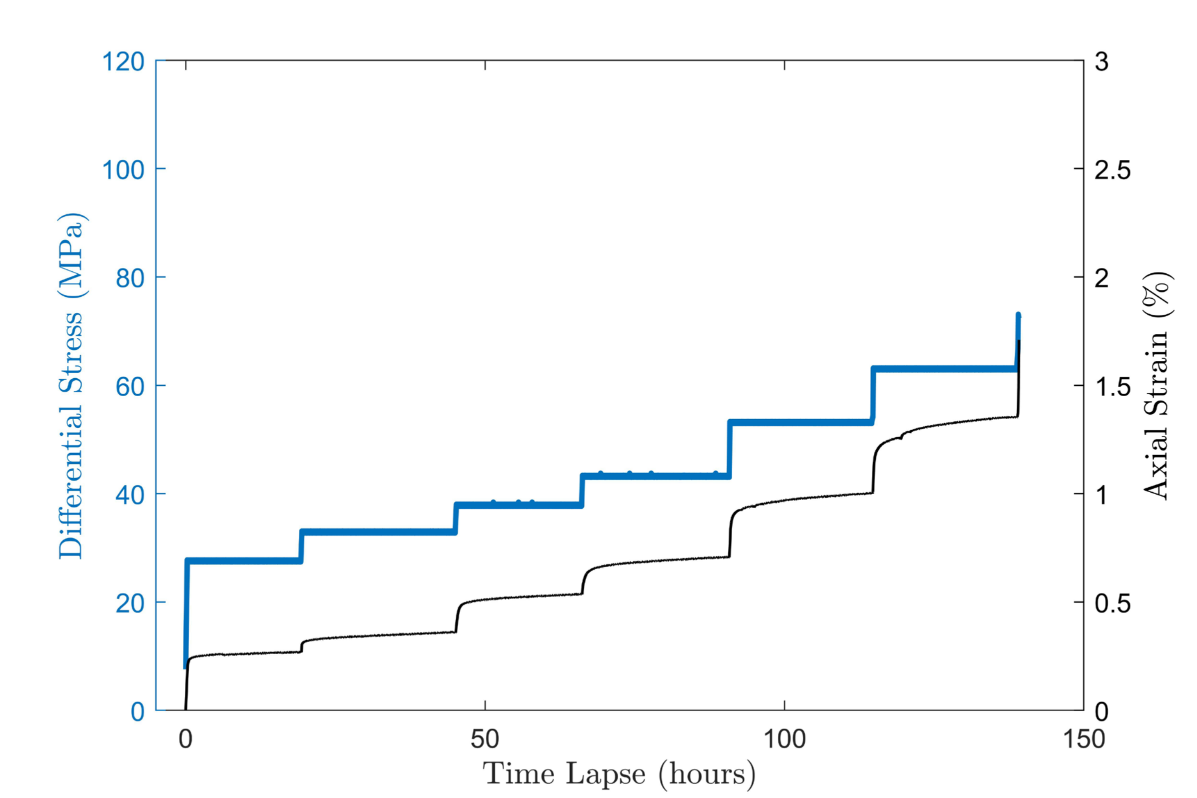
# Mechanical Data

**Saturated, T = 80˚C**

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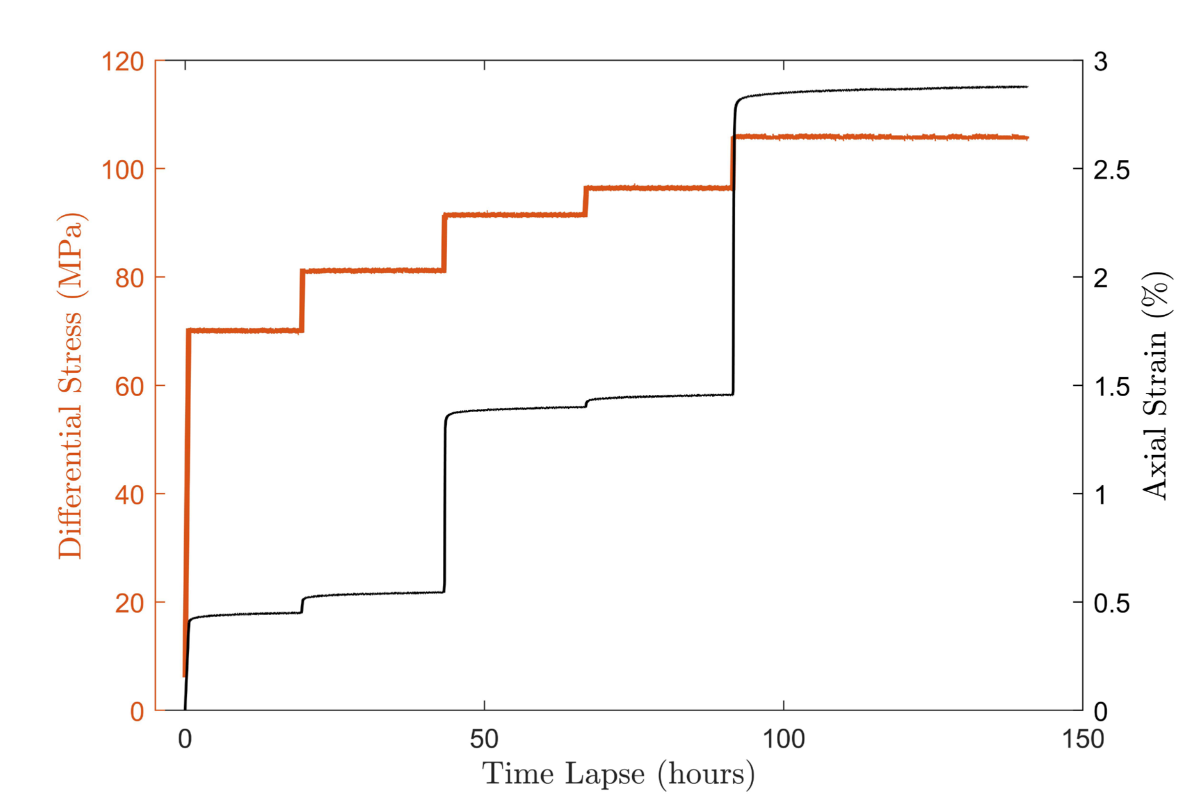

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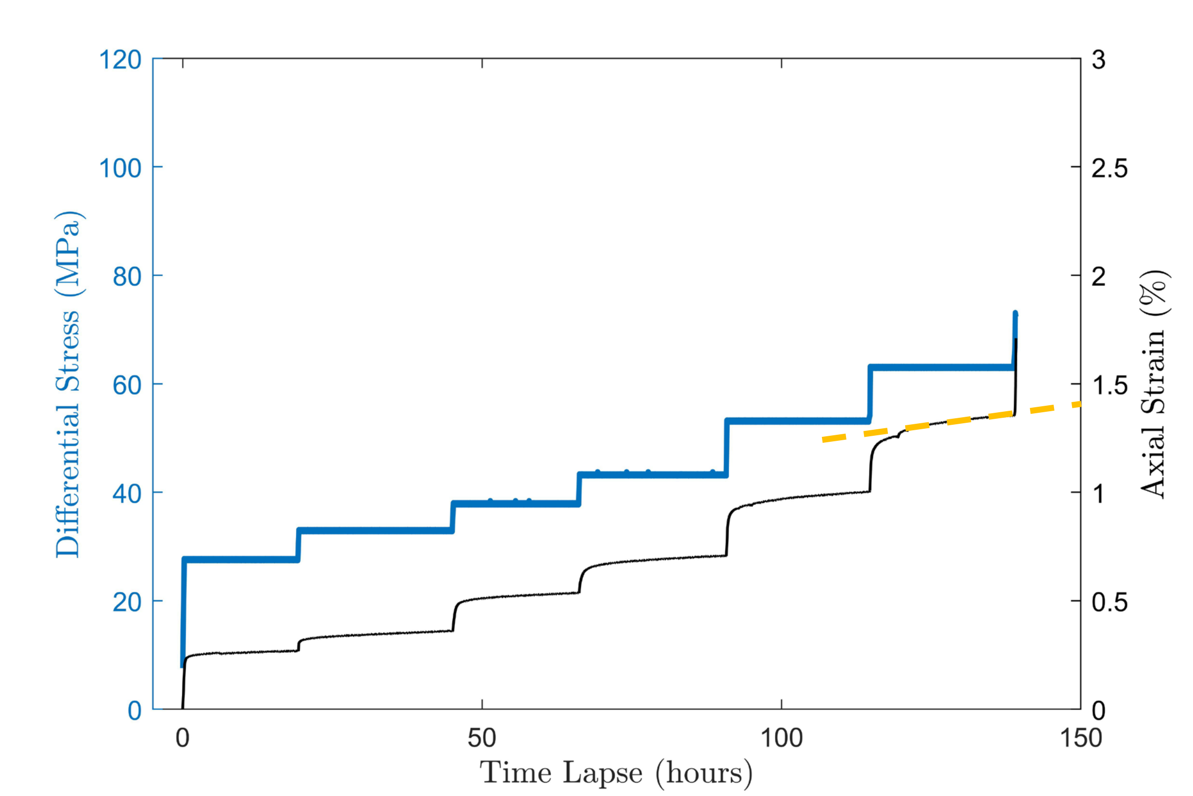


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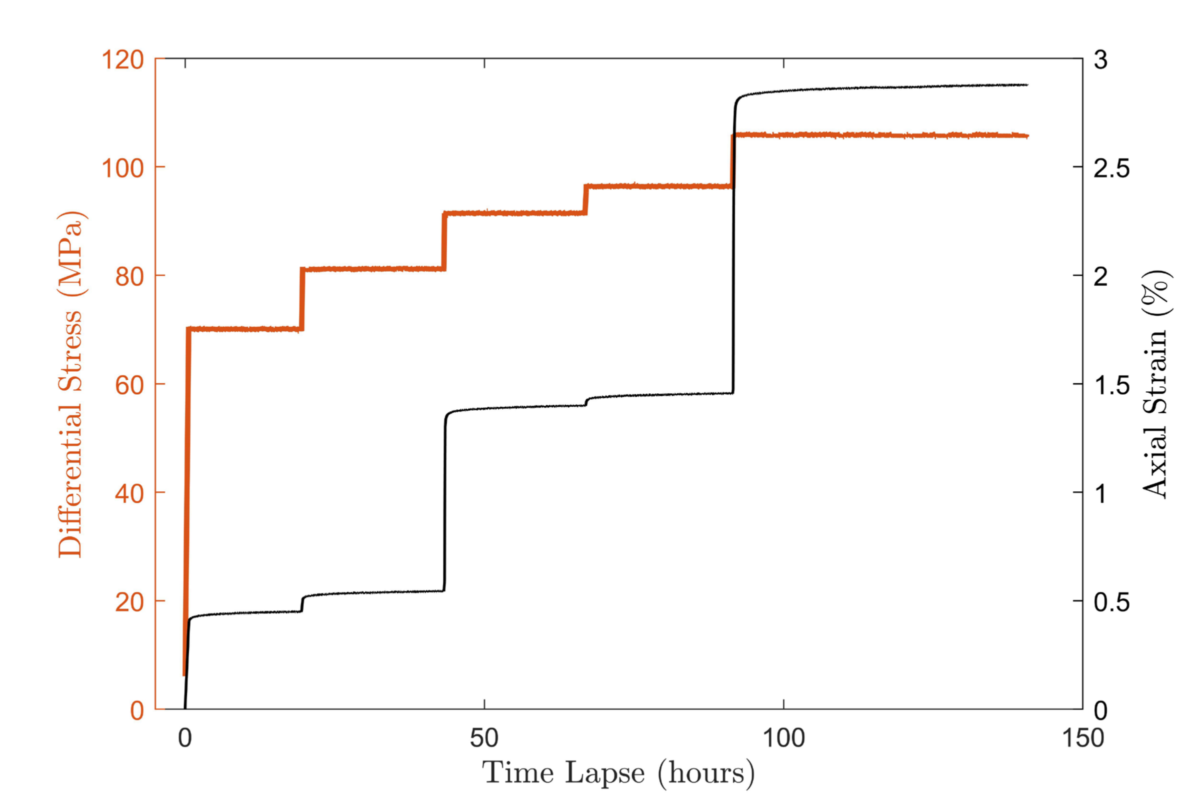
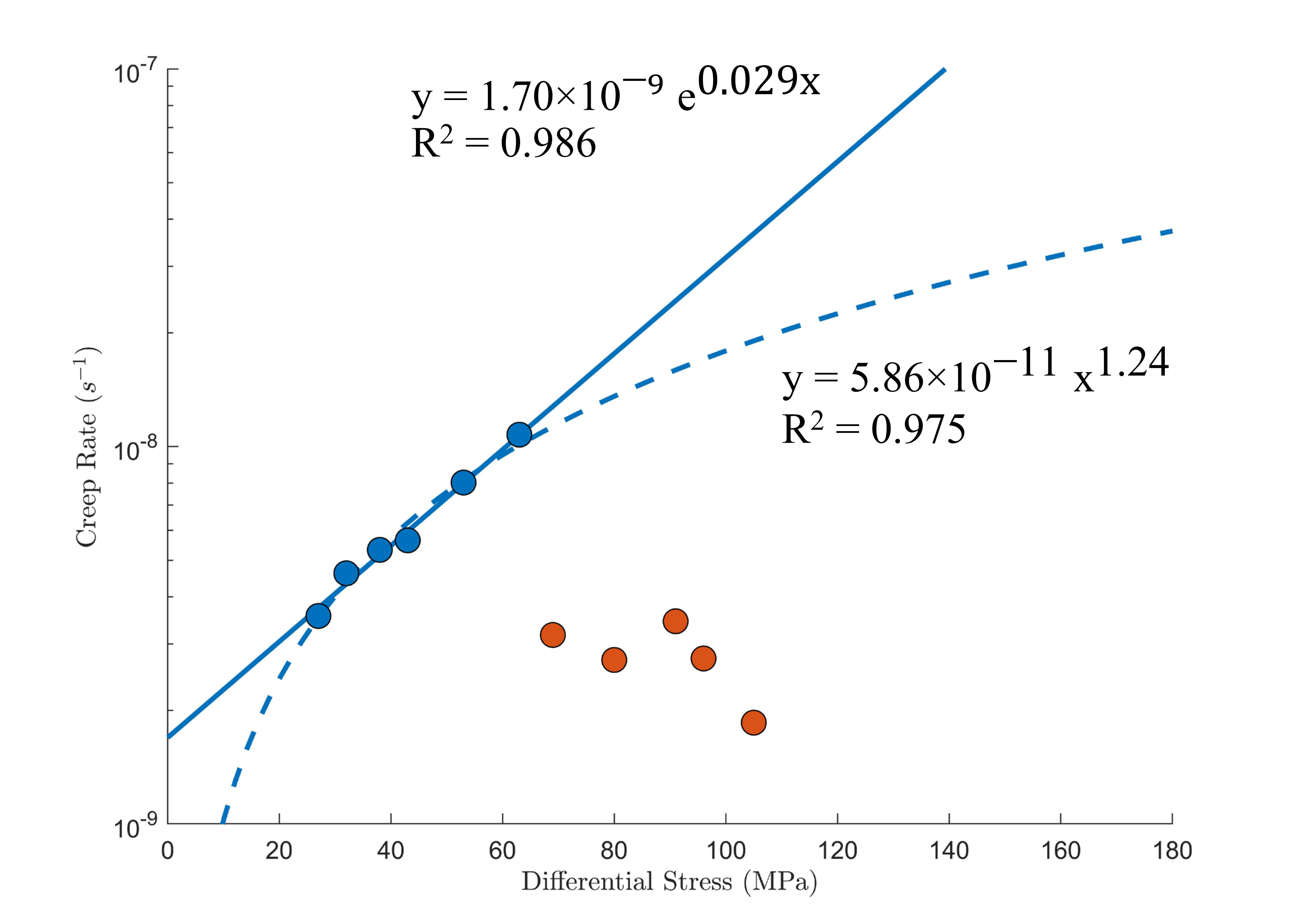


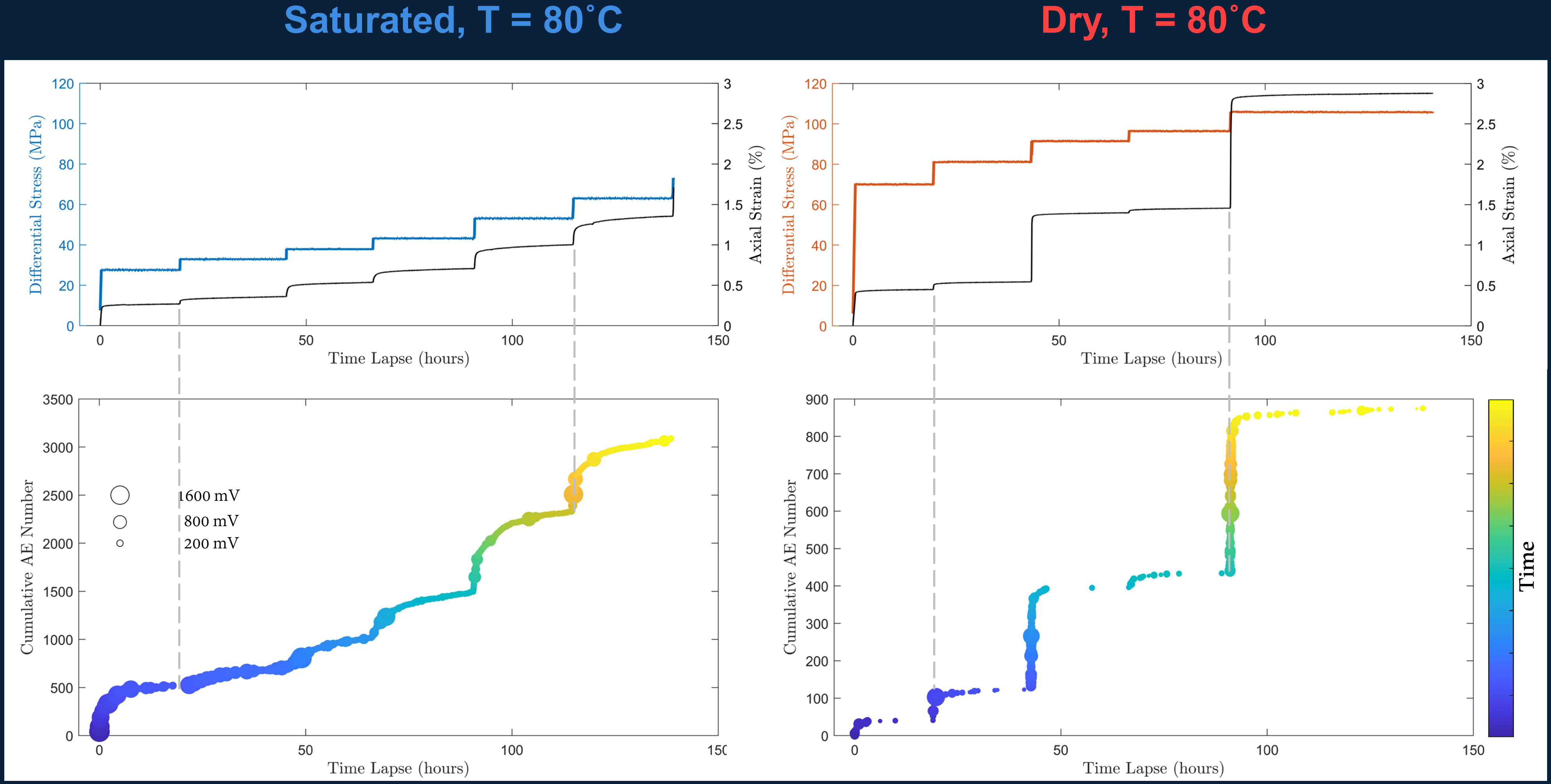
# Creep Rate

- **Creep rates in fluid-saturated experiment exhibit strong stress dependence compared to the dry experiment**



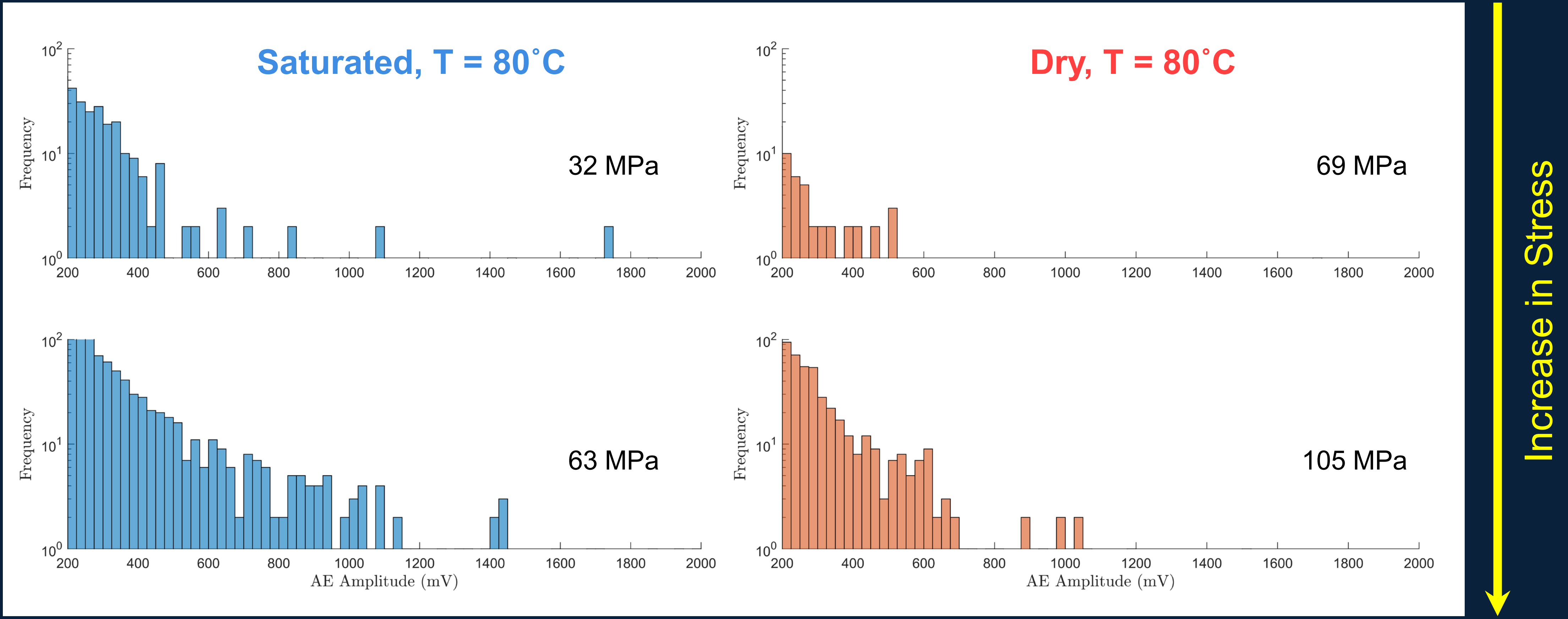
# Acoustic Emissions

- High AE rate during primary creep
- The AE rate dropped significantly within the first hour of the creep deformation
- AE events occur more frequently in the fluid-saturated experiment



# AE Amplitude

- More AE events with amplitude >200mV are observed in fluid-saturated experiment
- Stress increase promotes the occurrence of AEs



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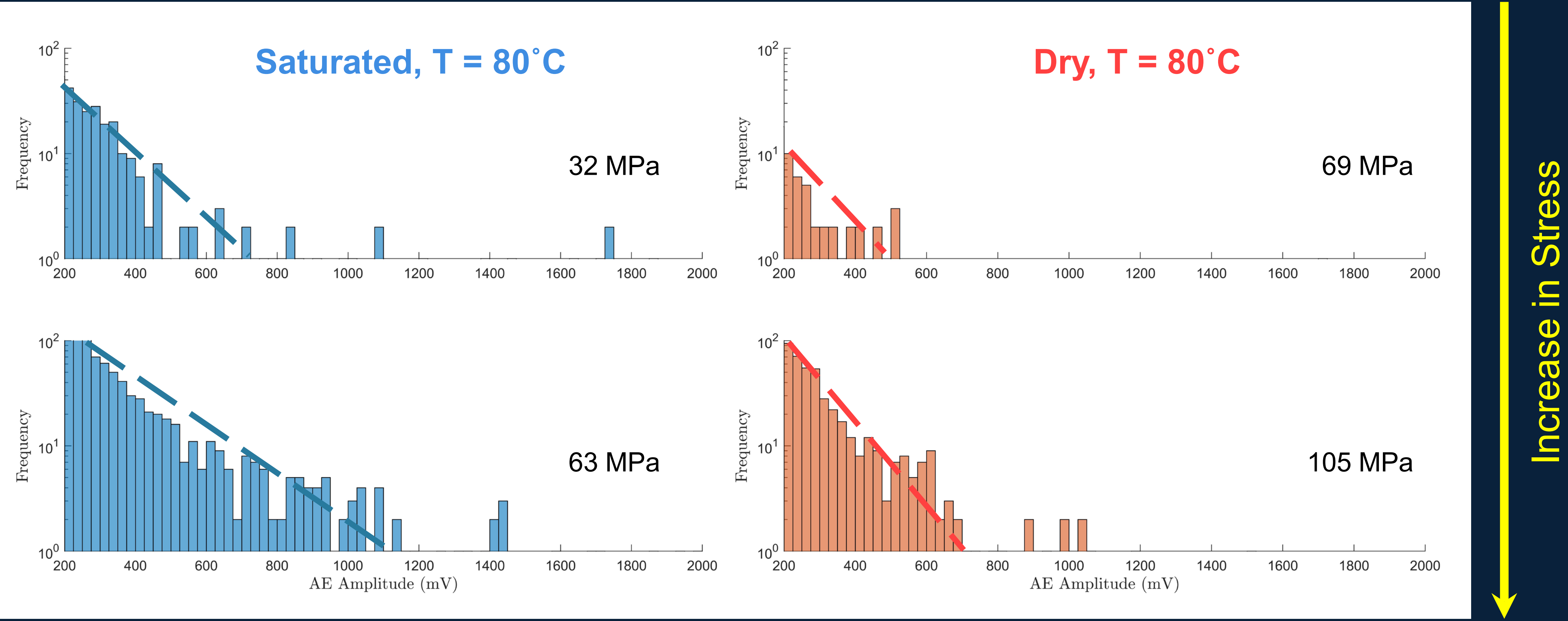


# Saturated Experiment

Before

After

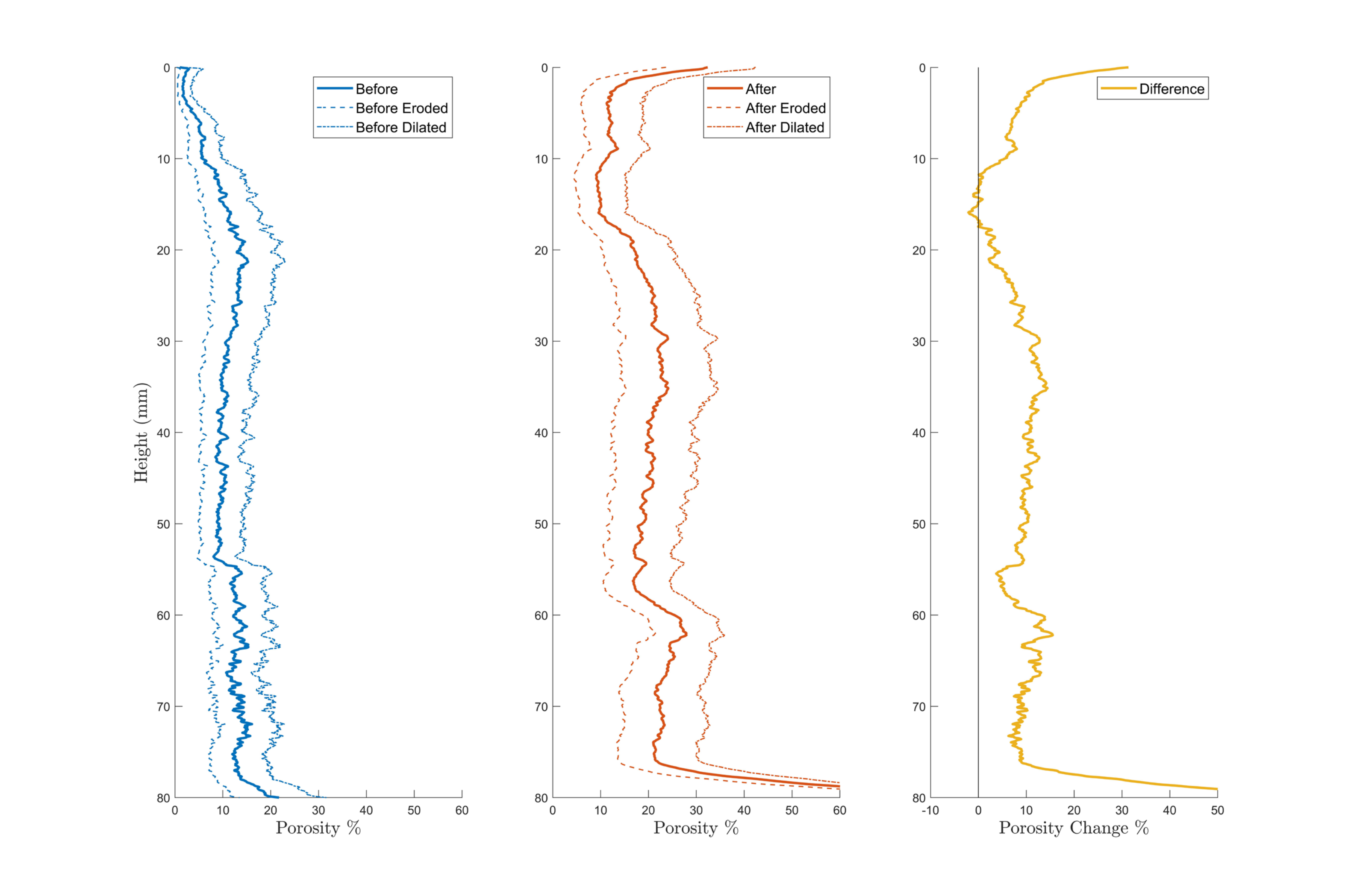
# Saturated Experiment

Pre-
existing
Pores

Newly-
generated
Pores

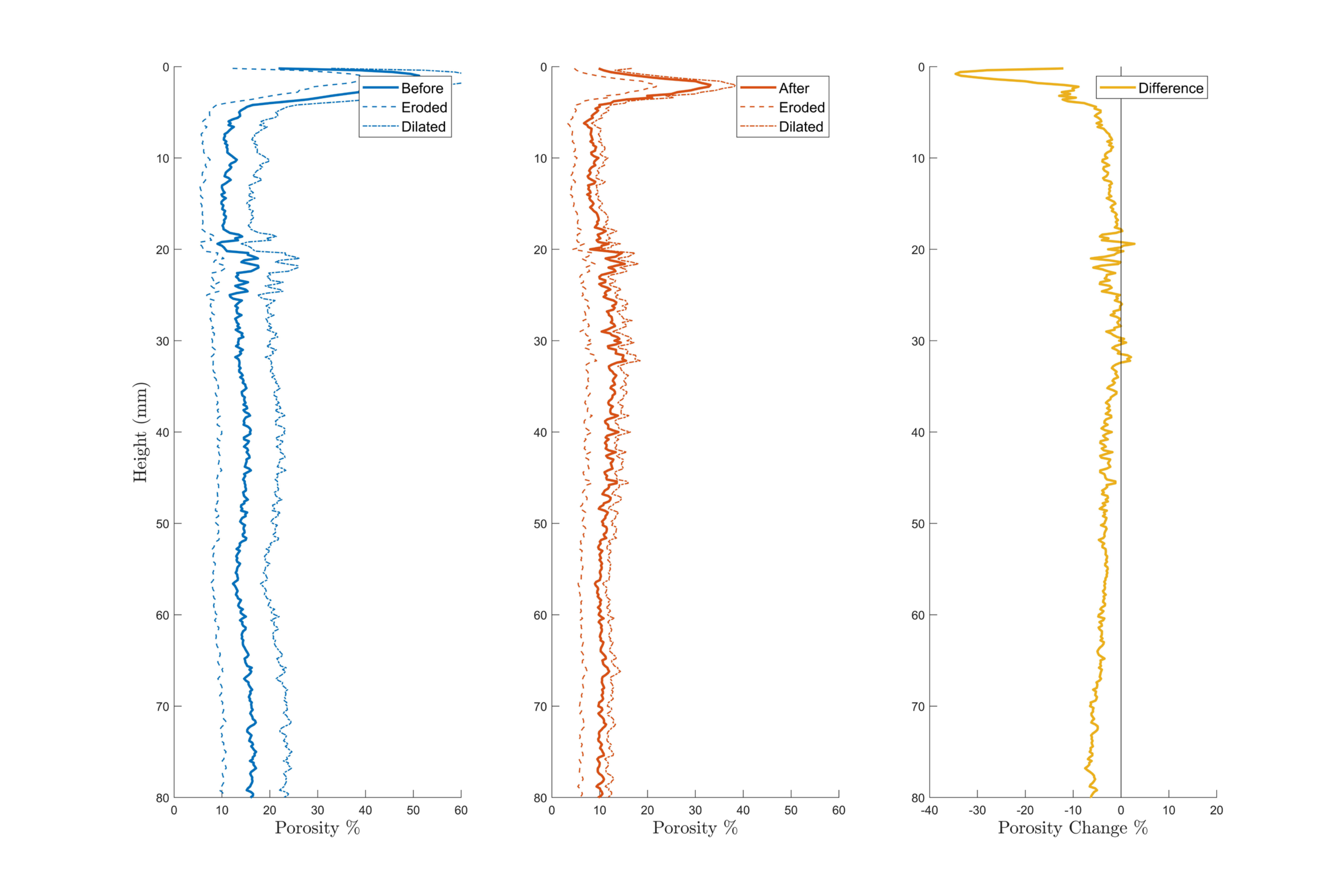
# Porosity Change (Saturated Sample)

- **Porosity increases during the fluid-saturated experiment**



# Porosity Change (Dry Sample)

- Porosity decreases during the dry experiment



# AE Location

Saturated

Dry

# AE Location

Saturated

Dry

# Summary

Results confirm that presence of fluid affects the creep deformation:

| | Water-saturated | Dry |
|---|---|---|
| **Strength** | Weak | Strong |
| **Creep Rate** | Strong stress-dependence | No obvious stress-dependence |
| **Porosity** | Increase due to dissolution | Decrease due to compaction |
| **AE Statistics** | More high amplitude events | Less high amplitude events |
| **AE Location** | Distributed | Localized |

- **Future work: creep experiments on rocks saturated with $CO_2$ rich fluid.**
- **Application: provide guidance to future applications of geological $CO_2$ storage**