

- Author names: Minsu Cha and Yunxing Lu
  - Organization name(s): Texas A&M University
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  - Abstract, 1-2 pages: See the abstract below.
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  - Photo of presenter:
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- Bio of presenter:

**Title: Thermal Fracturing Behavior in Well Stimulations of Enhanced Geothermal Systems - Experimental Studies**

**Abstract**

Geophysical indications show evidences of inherent thermal effects existing in stimulations of enhanced geothermal systems (EGS) reservoirs due to large difference in temperature between injected fluid (water) and hot rock, but the detailed mechanisms of thermal effects on fracturing in downhole conditions are not well understood. Observations of the thermally induced fractures and effects from field geophysical indications such as from surface and observation wellbores are limited because it may not provide information about accurate stimulation mechanisms working deep under the ground. Thus, this study investigates the behaviors of thermally induced fracturing in a laboratory environment relevant to EGS reservoirs.

We developed a laboratory system for modeling thermal stimulation and fracturing in an environment resembling EGS downhole conditions. Tests are performed using unconfined cubic specimens (8"×8"×8") of concrete and granite with boreholes and partial casings. The specimen is placed in the oven, and slowly heated to 200-250 °C. Room-temperature water is then injected into the borehole through the inlet tubing, and then flown out. The flow was under low pressure, which allows to see the effect of thermal shock only. Sharp thermal gradient created at the surfaces of formation rocks causes strong local tensile stress and initiate fractures. Unlike pressure-based fracturing, such as hydraulic fracturing, in this study, the wellbore is subject to continuous flow through the wellbore to maximize thermal shock effects. After flowing water for 10-20 minutes through the borehole, the specimens underwent breakdown pressure to fully fracture to the outer surface. Temperature in boreholes and block surfaces and fluid pressure in boreholes were monitored. Acoustic and pressure-decay measurements were obtained before and at various stages of stimulations.

Results showed that the front of thermally induced fractures is clearly identified by dye; the thermally driven fractures were initiated from the borehole surfaces and propagated adjacent to the boreholes to some extent. The “seed” fractures created during thermal stimulation reduced breakdown pressure levels measured subsequently. The results are of significance in reservoir stimulations because the thermal seed fractures are likely to reduce breakdown pressure levels in pressure-based fracturing (e.g., hydraulic fracturing). The temperature of borehole wall dropped quickly upon initial water flow, indicating minimum film boiling effect at the borehole surface, unlike significant film boiling observed at cryogen-rock contact in the cryogenic treatment which is aimed for hydrocarbon reservoirs. This implies efficient thermal transfer between water and hot borehole surface, which is favorable for thermal treatment. Decreased acoustic velocities and amplitude after the stimulation well indicated thermally induced micro-

and major fractures. The profiles of borehole pressure decay obtained before and after each stage of stimulation show that thermal flows increase the permeability of treated specimens. Multiple treatments showed that increasing number of stimulations increases permeability by furthering fracture propagation and creating new fractures.

The knowledge obtained in this study may be applicable to wellbores that need stimulation such as enhanced geothermal wellbores and other underground resources and environmental projects. Thermal fracturing may also be used in combination with other stimulation technologies. In particular, the technique may help in the field to lower the breakdown pressure by creating seed fractures prior to a pressure-based treatment. The thermal fracturing processes may actively engineered to increase the efficiency of hydraulic fracturing. The results may reduce uncertainties in practices or strategies in considering thermal stimulation effects in hydraulic fracturing to create efficient EGS reservoirs, and thus allow favorable utilization of thermal stimulations.

SMU Geothermal Conference  
January 10-11, 2018

# Laboratory thermal fracturing of wellbores - Implications in enhanced geothermal systems and unconventional reservoir stimulations

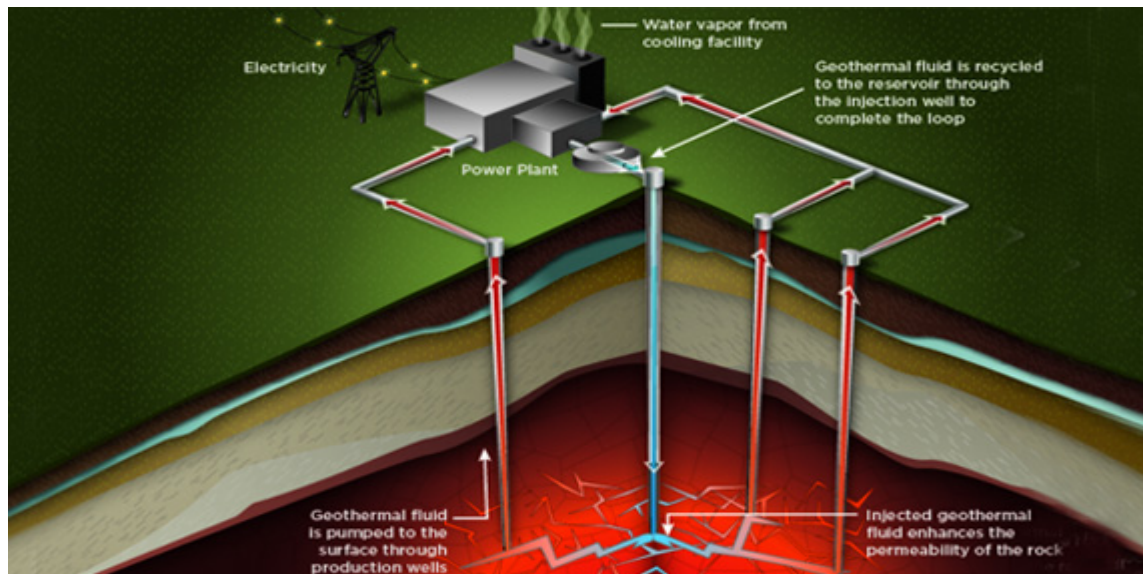
Minsu Cha & Yunxing Lu

1/10/2018

Zachry Department of Civil Engineering  
Texas A&M University

# Enhanced Geothermal System – Hot dry rock

- Deep (~3-8km) hot dry rock with little natural permeability
- A borehole drilled to the desired depth and reservoir is created by hydraulic fracturing.
- Water is injected and hot water is collected from another borehole.

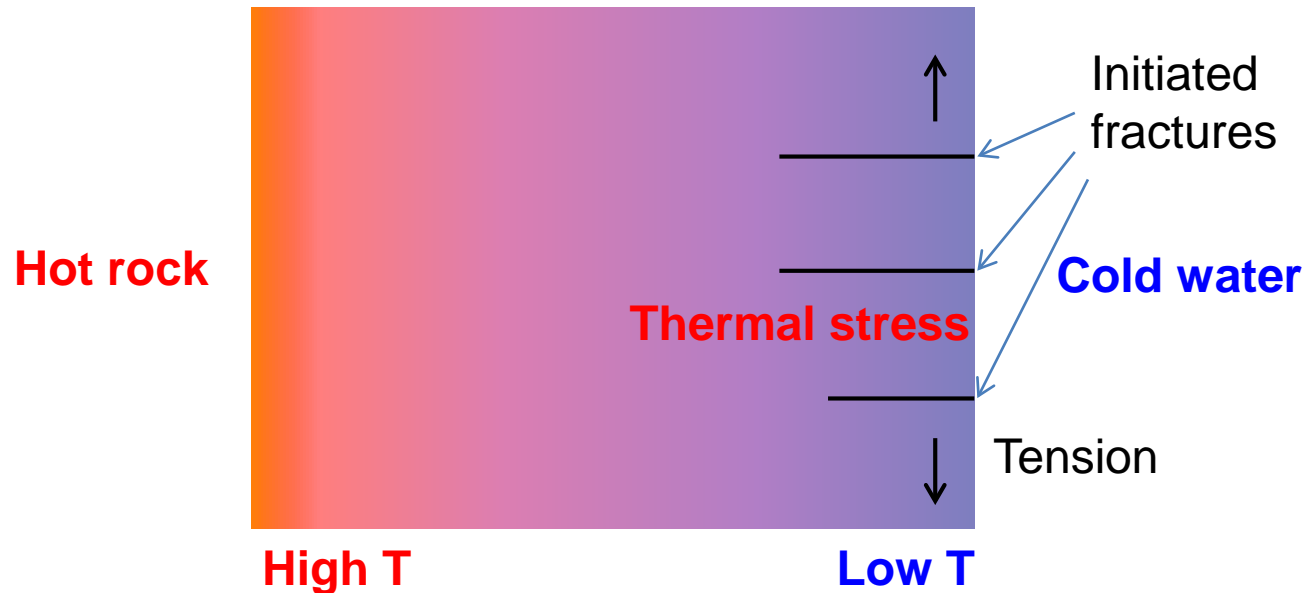


# Motivations

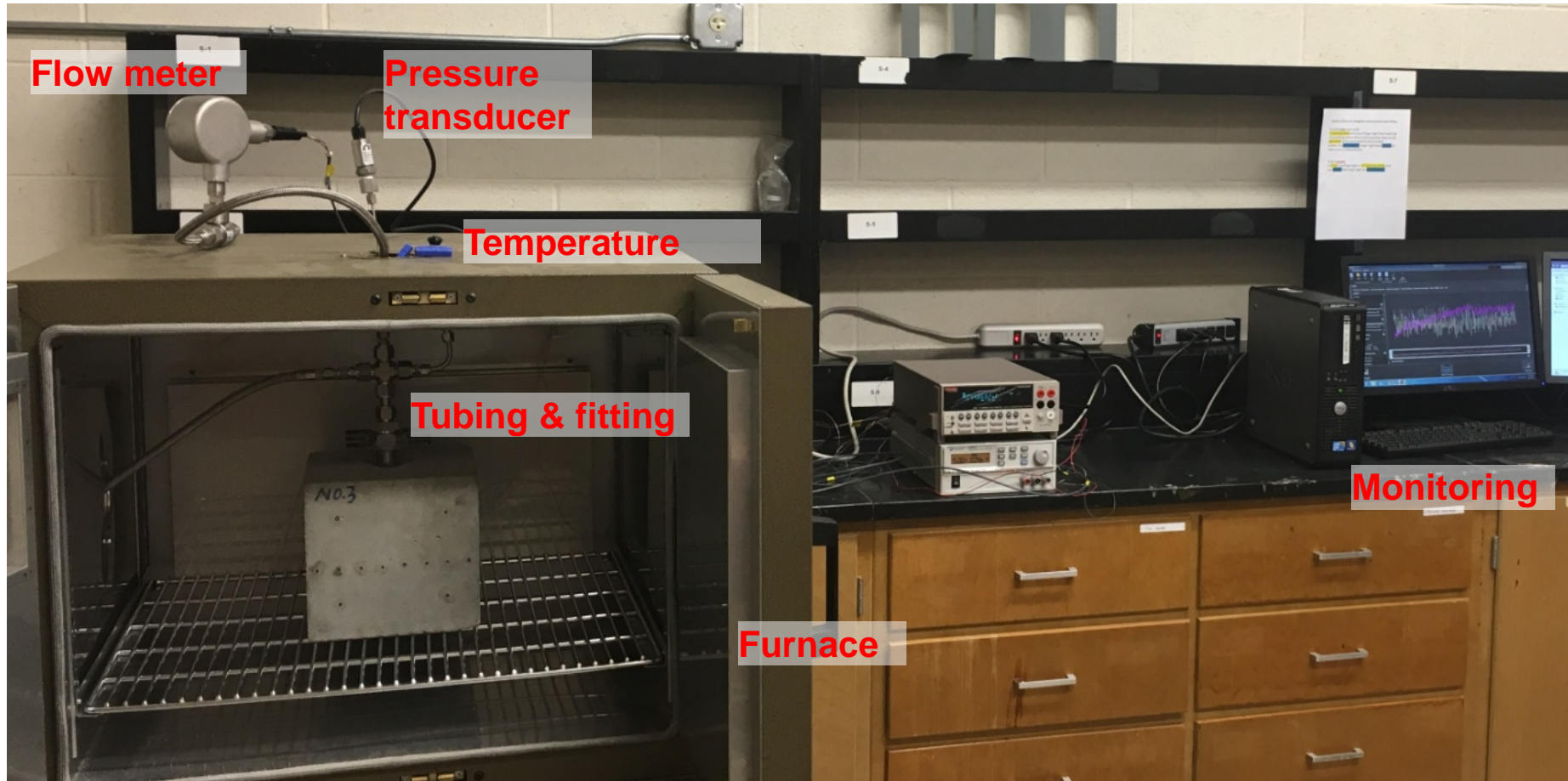
- Inherent thermal effects expected due to large temperature between injected fluid and hot rock
- Geophysical indications shows significant thermal effects during EGS hydraulic fracturing (e.g. delayed induced seismicity)
- Downhole thermal effects not well understand; in particular thermally induced fracturing in downhole environment needs further understanding.

# Thermal Fracturing - Basic Concept

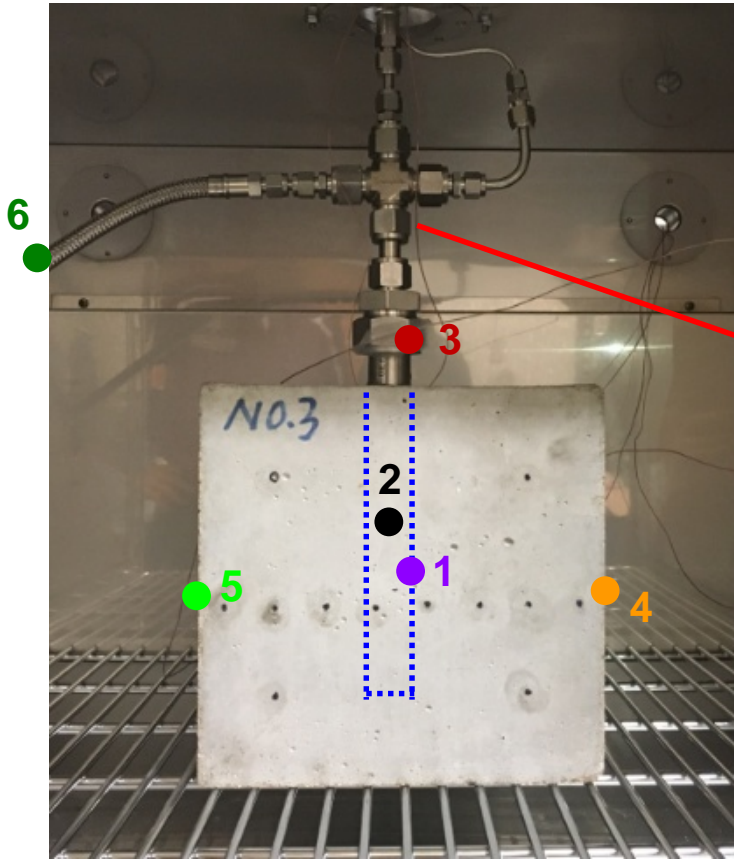
- Hydraulic frac uses high fluid pressure to fracture rocks.
- Thermal fracturing uses large temperature difference to induce local thermal stress and contraction to overcome tensile strength & initiate fractures.
- Pressure may be applied to borehole/reservoir to further propagate fractures.
- Water is used for fracturing and it is also carrying heat energy.



# Thermal fracturing laboratory

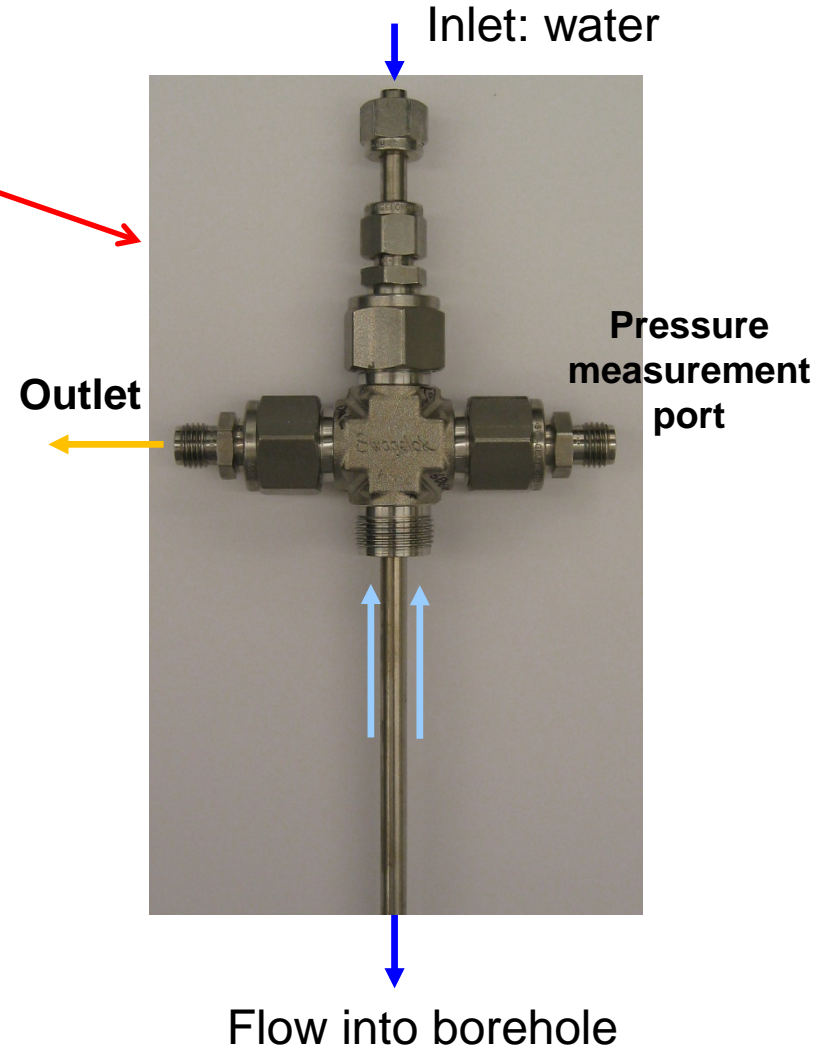


# Thermal fracturing laboratory



Temperature measurement locations

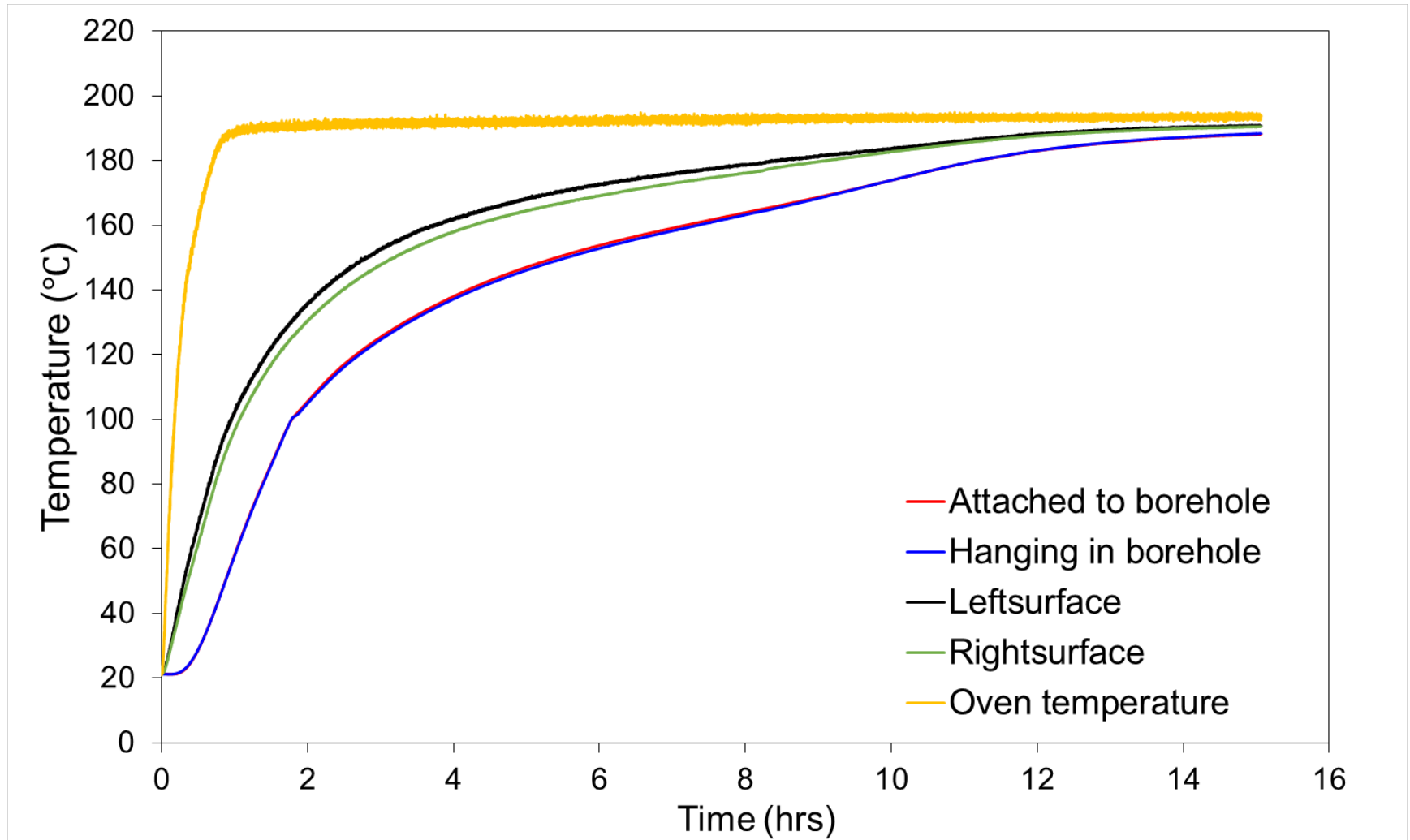
Water flow through





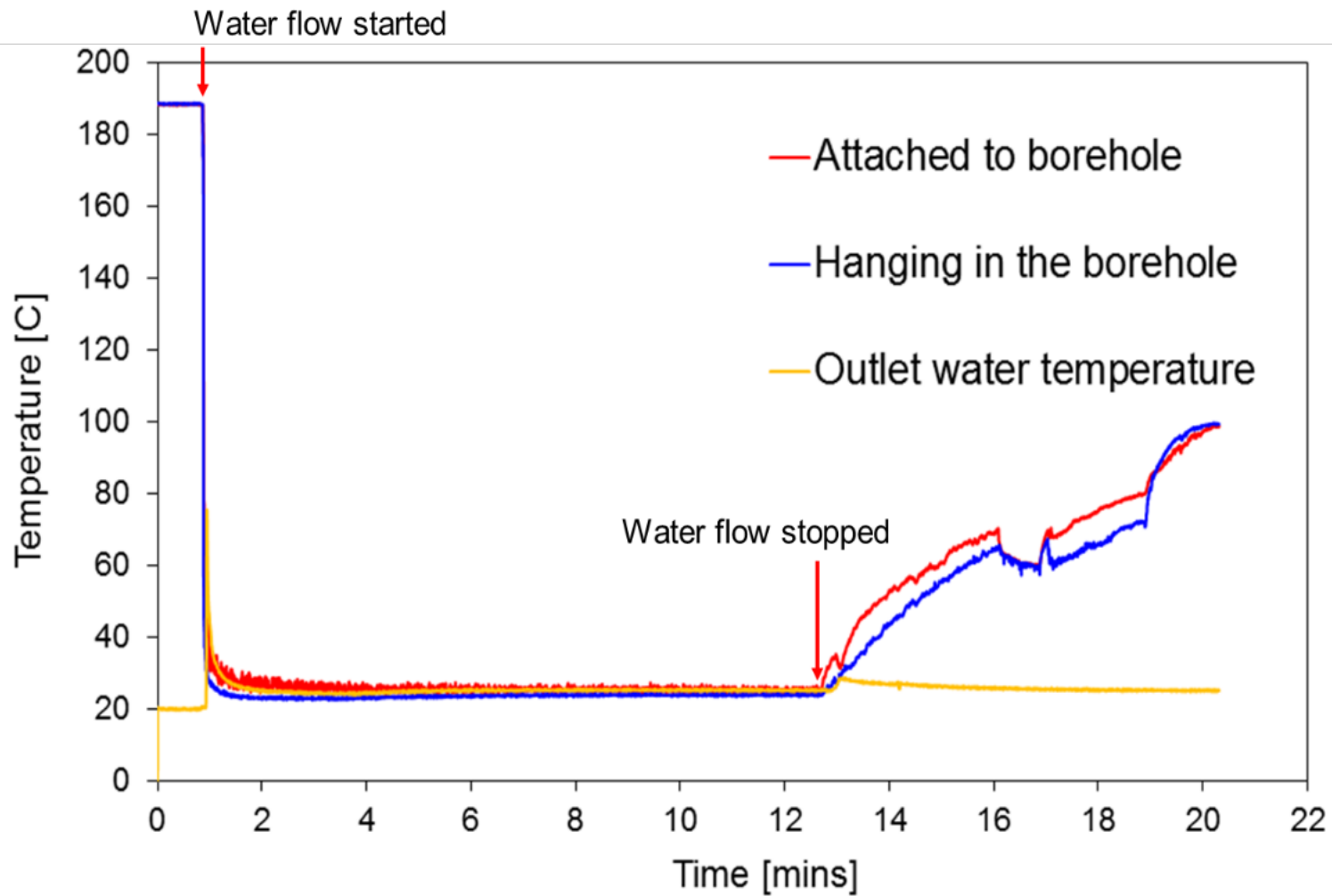
Water flow through  
hot concrete borehole

# Temperature - Heating



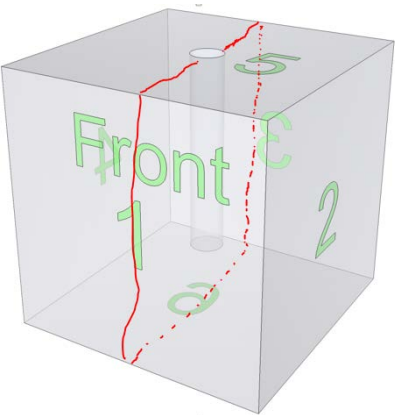
(Test #15; Specimen #7)

# Temperature - Water flow



(Test #15; Specimen #7)

# Fracture assessments: Bubble generation



Surface 1

Before heating



After test (ambient temperature)



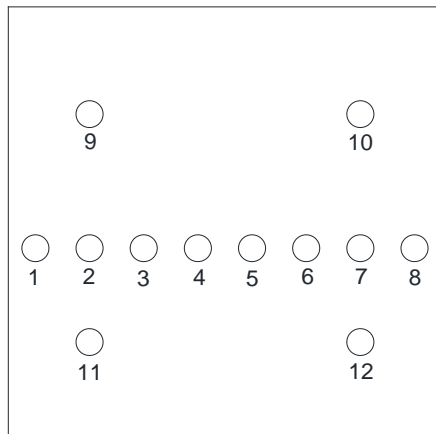
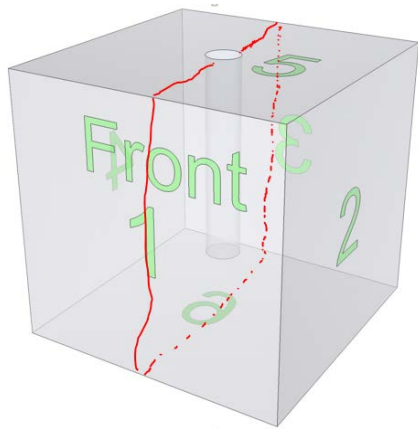
- \*Visible fracture observed after thermal stimulation
- \*Constant borehole pressure 40 psi
- \*Time passed: 2 mins

(Face 1, Specimen #7)

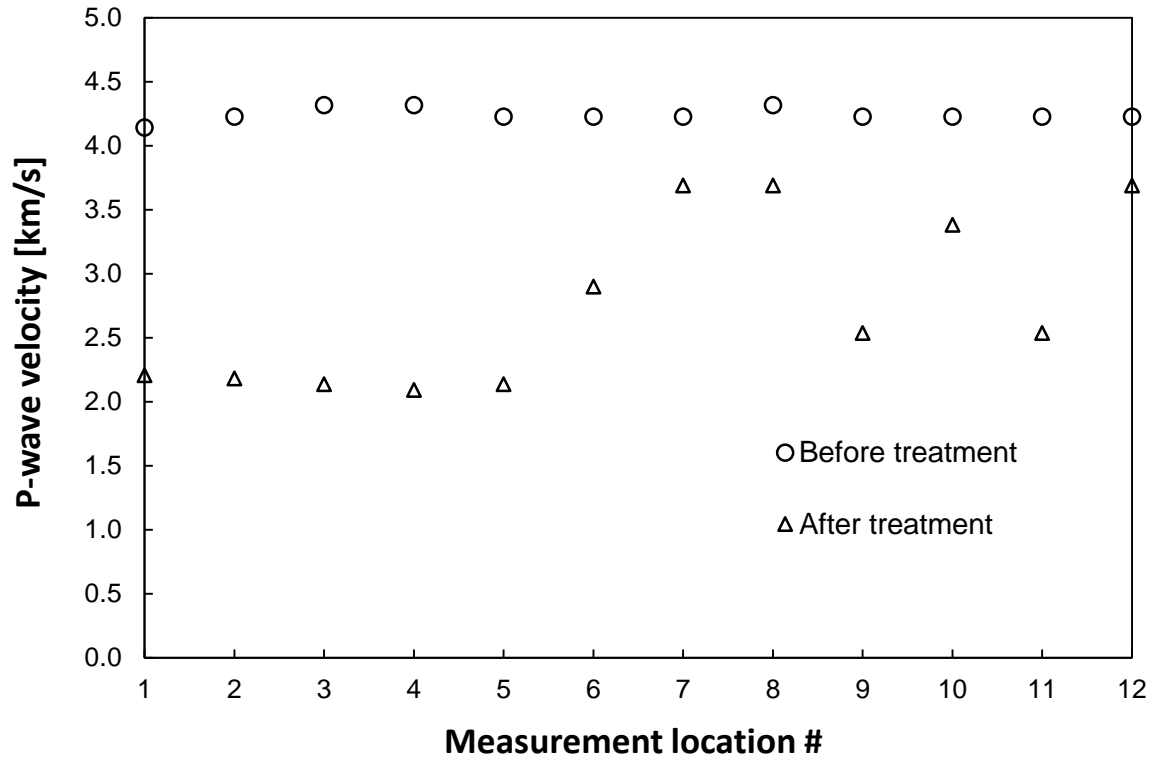
# Fracture assessments: Acoustic velocity

P-Wave velocity

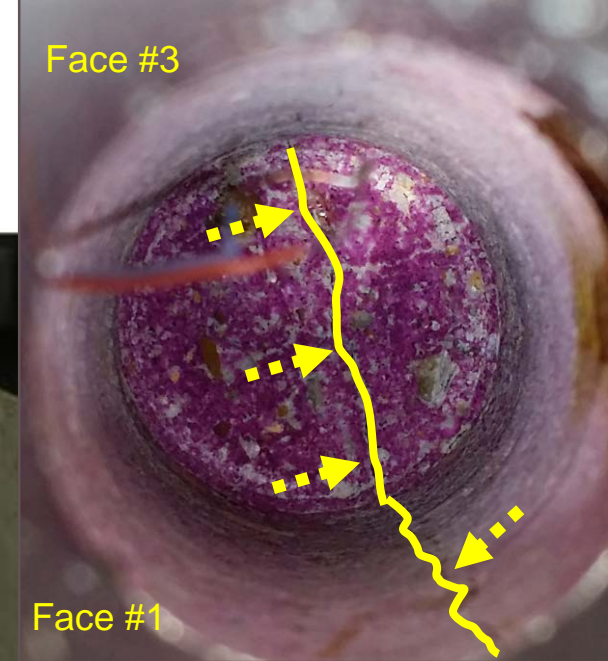
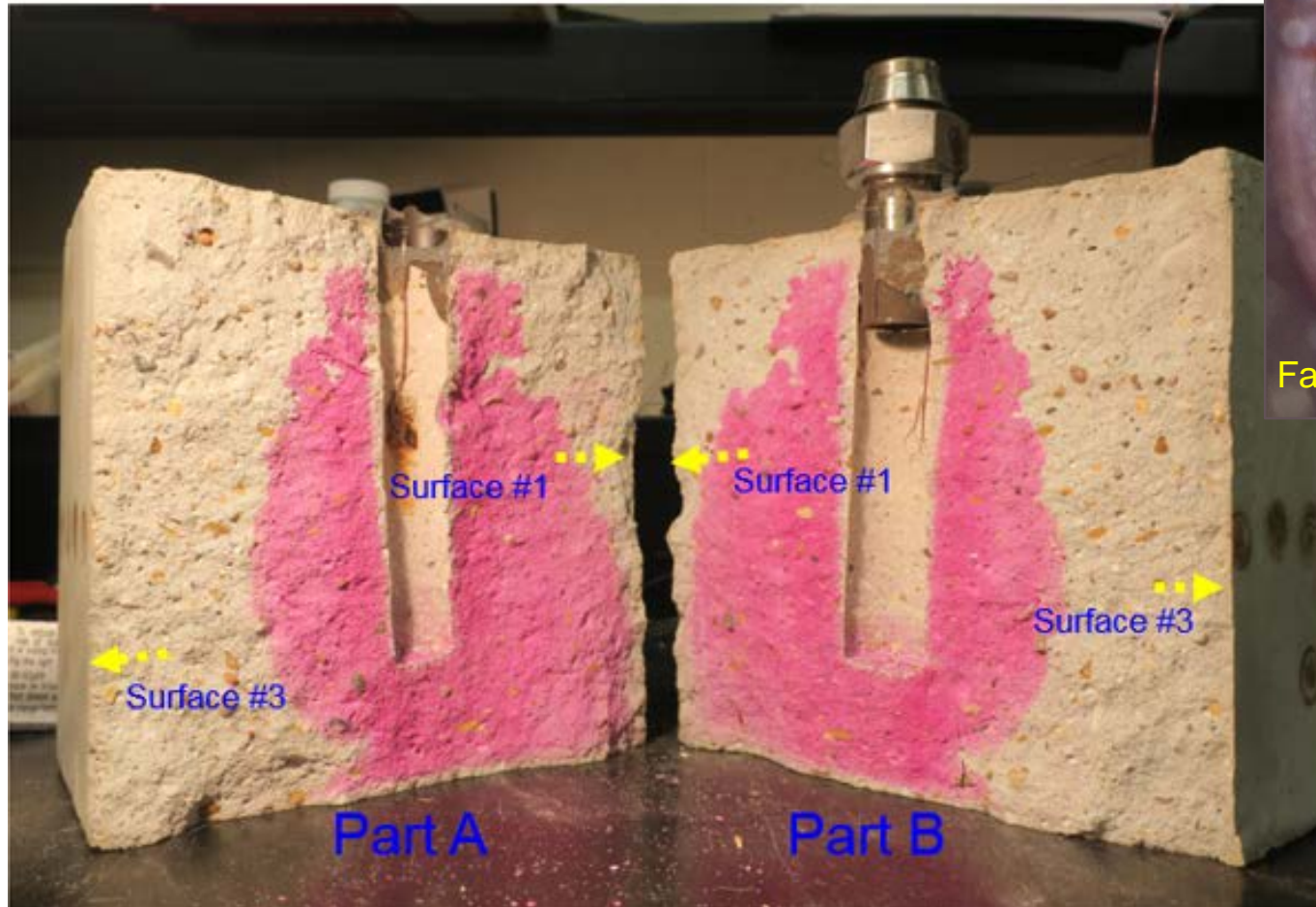
Specimen #14



Face 2&4



# Thermal fracture front

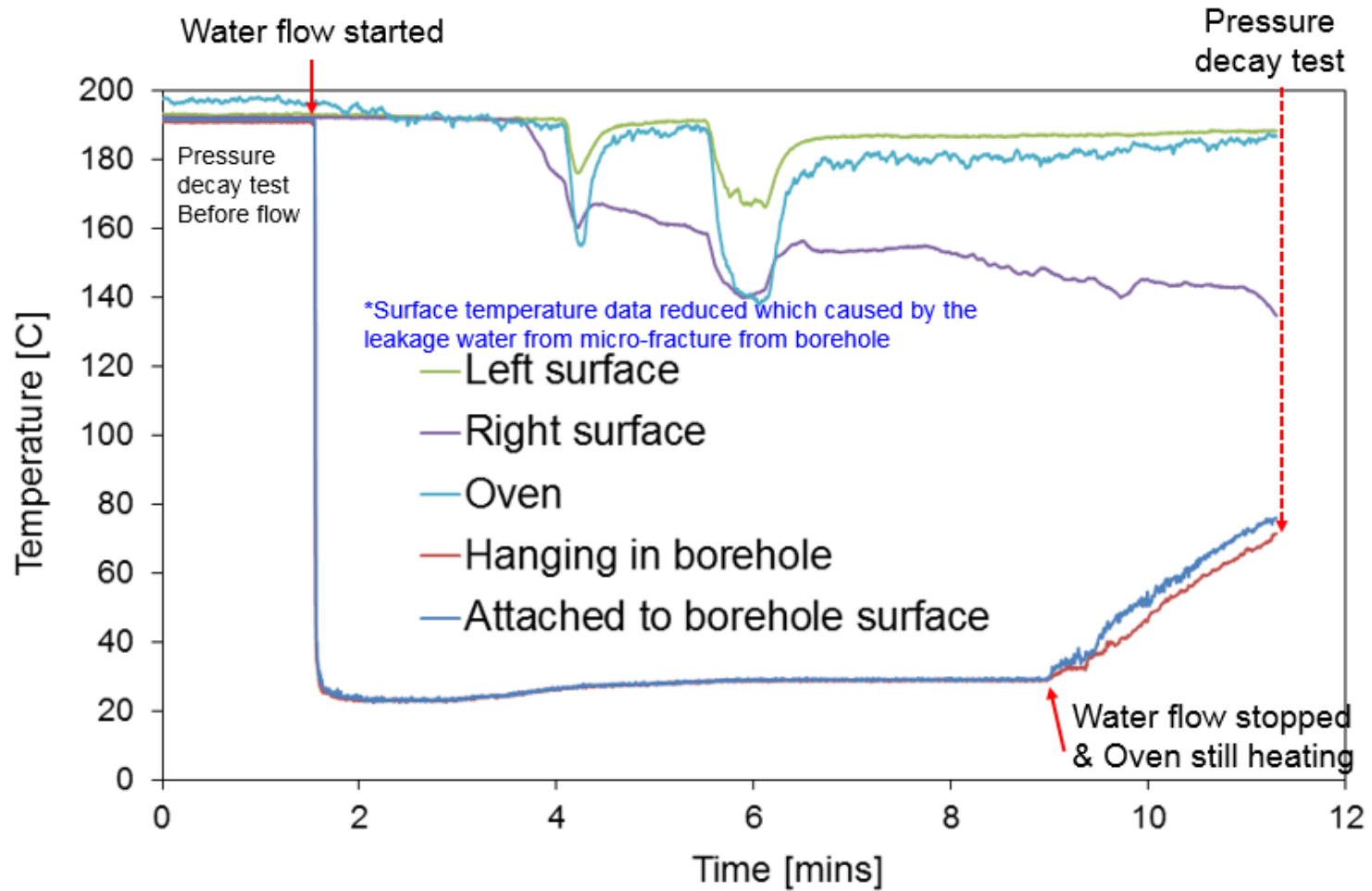


Breakdown test results (colored by phenolphthalein)  
(Specimen #14)

Water flow through  
hot granite borehole

# Temperature - Water flow

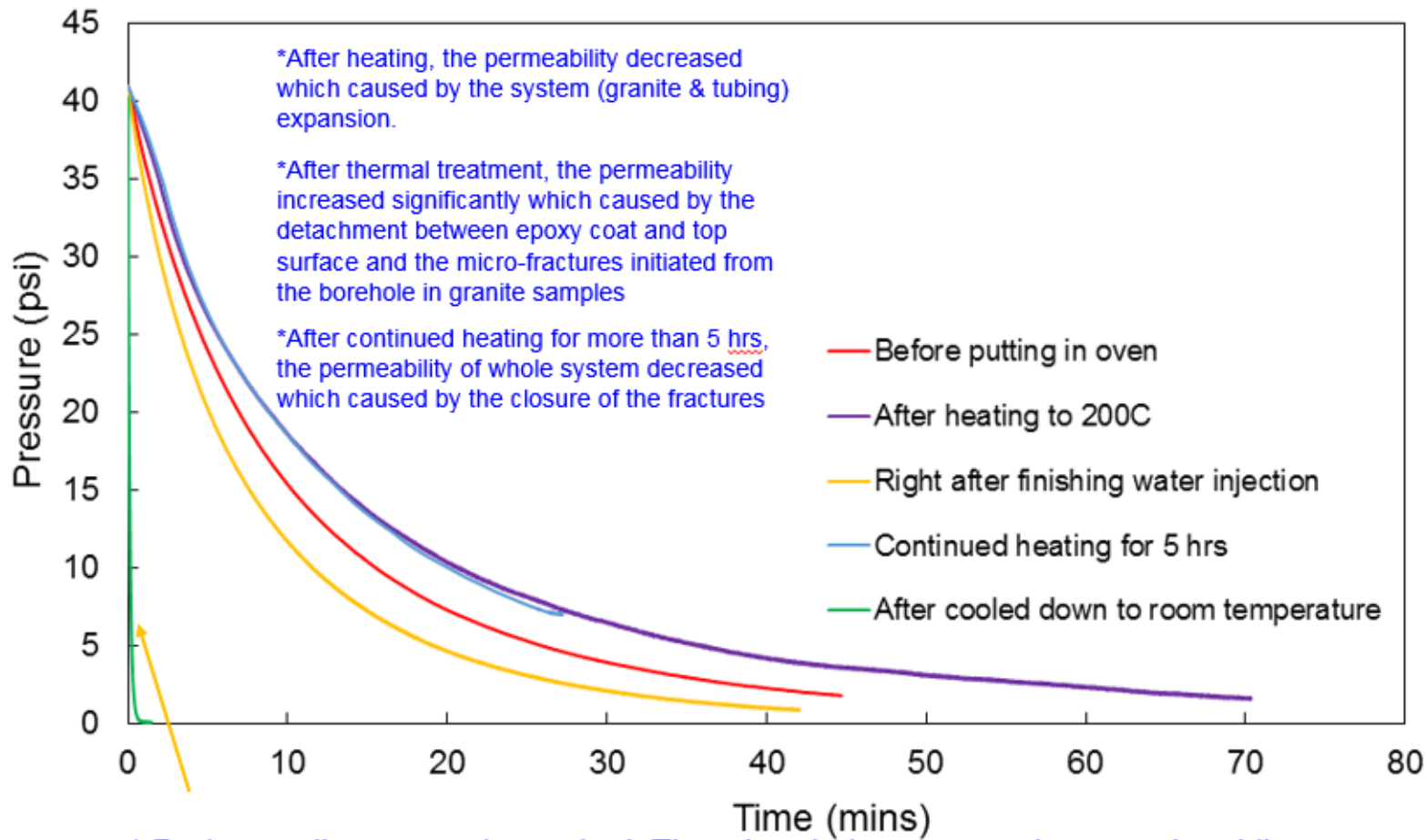
\*Heated for 8.5 hrs before water flow



Granite block Specimen #2 (the first stimulation)



# Fracture assessments: Pressure decay tests



\* During cooling, epoxy is cracked. Thus, borehole pressure decreased rapidly during the pressure decay test.

Granite block Specimen #2 (the first stimulation)

# Fracture assessments: Bubble generation

## Surface 4

\*Before heating



\*After test (ambient temperature)



\*Constant borehole pressure 40 psi

\*Time passed: 2 mins

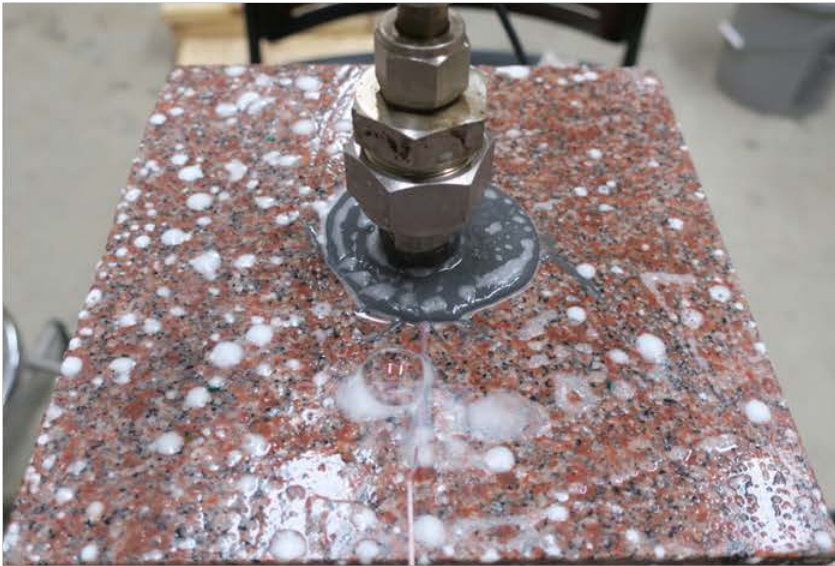
Comparison of bubble leakage before and after the first stimulation (Face 4, granite Specimen #2).

# Fracture assessments: Bubble generation

## Surface 5

\*Before heating

\*After test (ambient temperature)



\*Visible fracture observed after thermal stimulation

\*Constant borehole pressure 40 psi

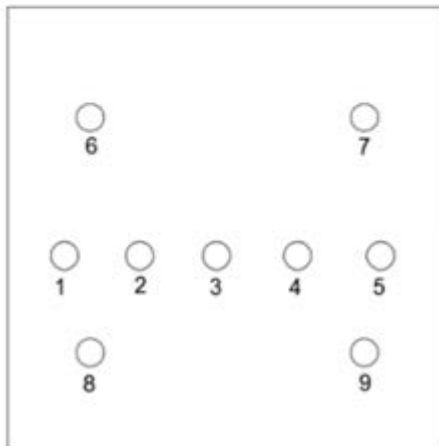
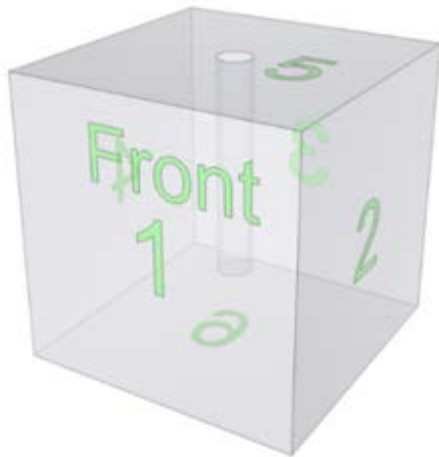
\*Time passed: 2 mins

Comparison of bubble leakage before and after the first stimulation  
(Face 5, granite Specimen #2).

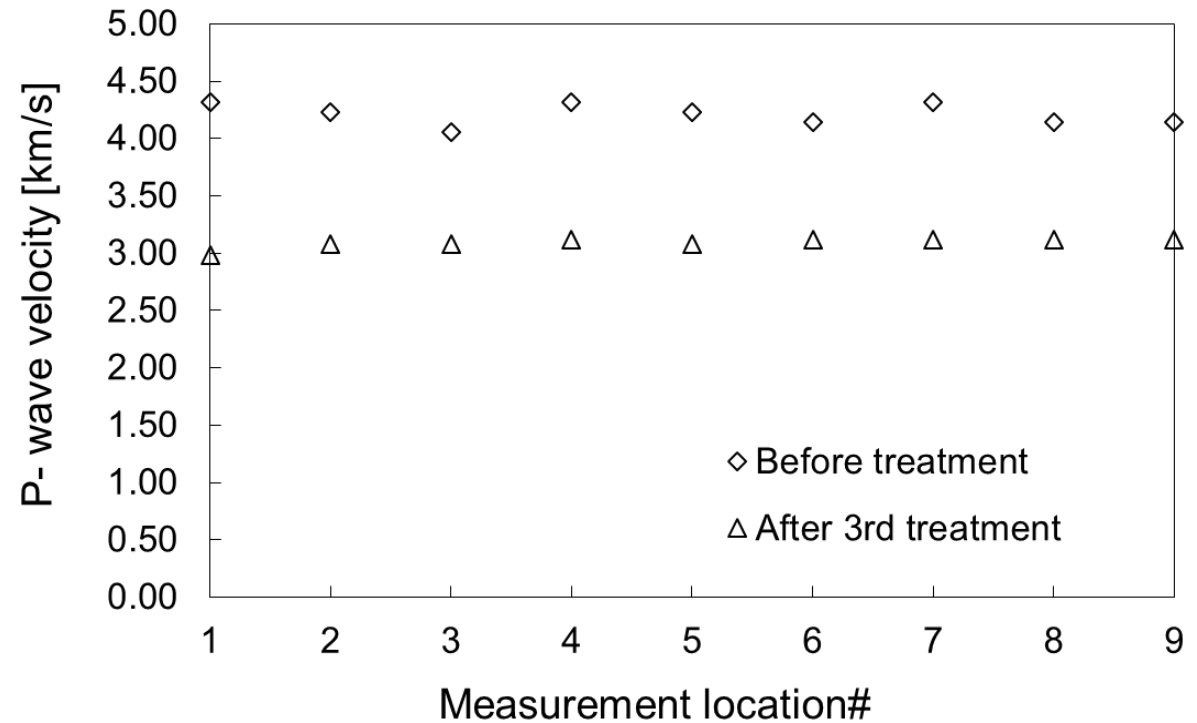
# Fracture assessments: Acoustic velocity

## P-Wave velocity

Granite specimen #1



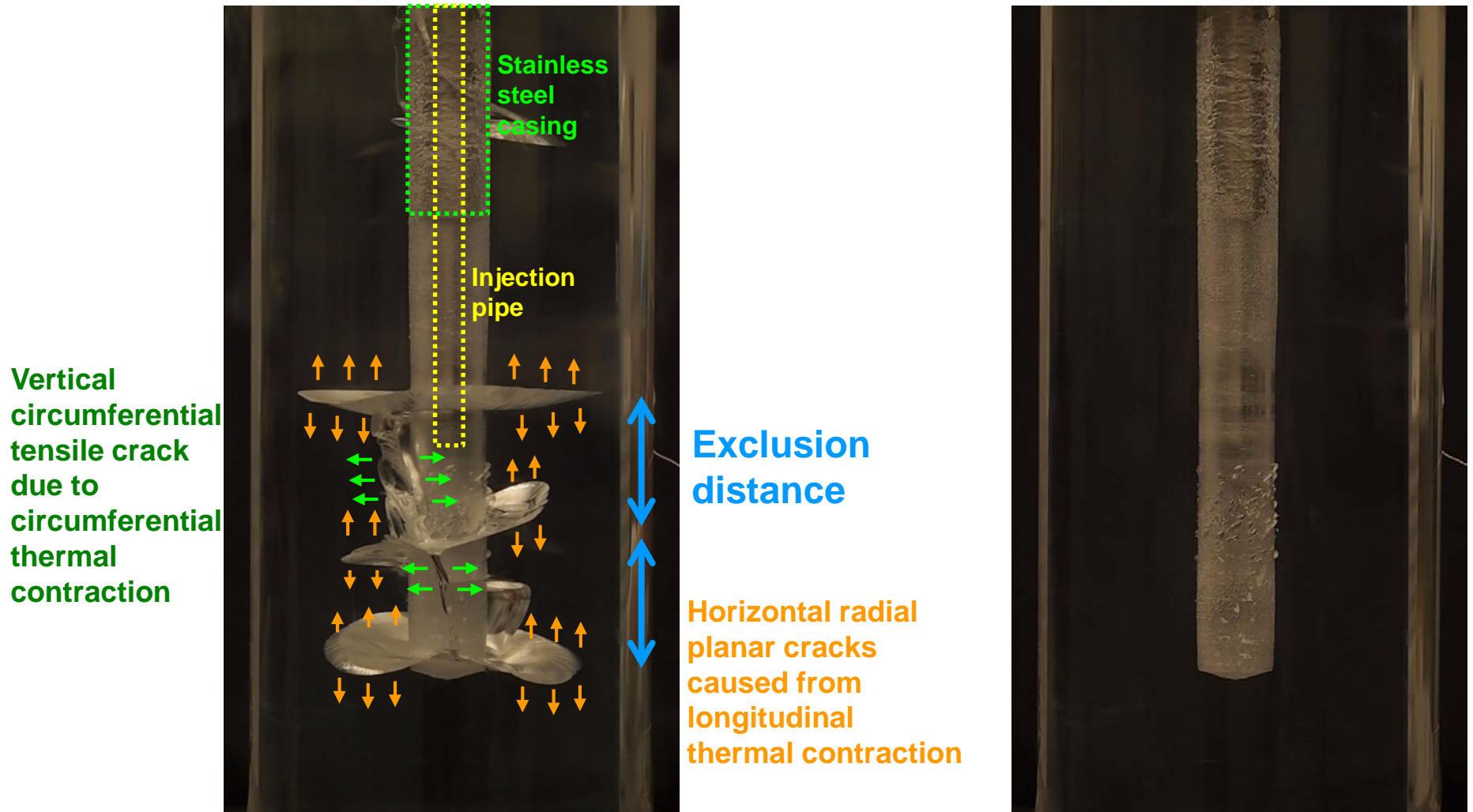
Face 1&3



Liquid nitrogen on room-  
temperature borehole

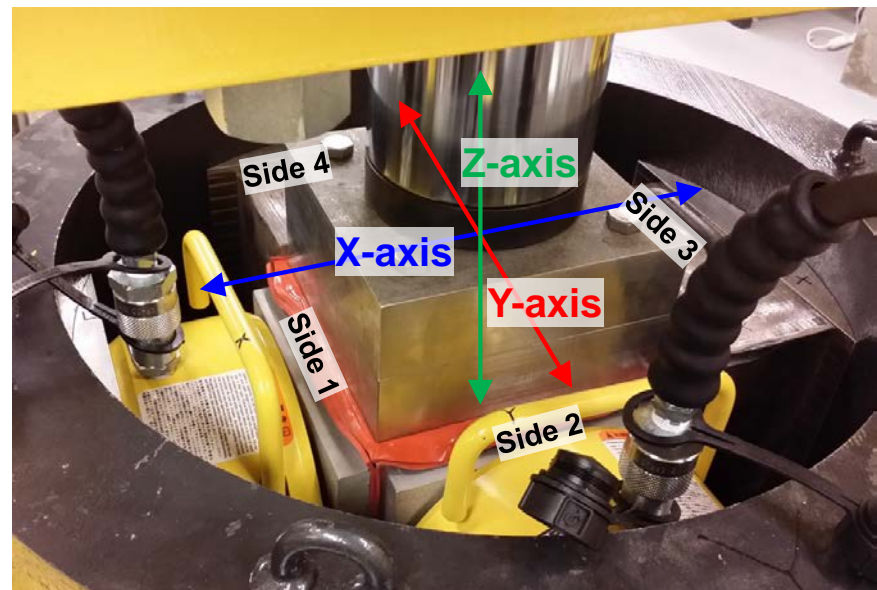
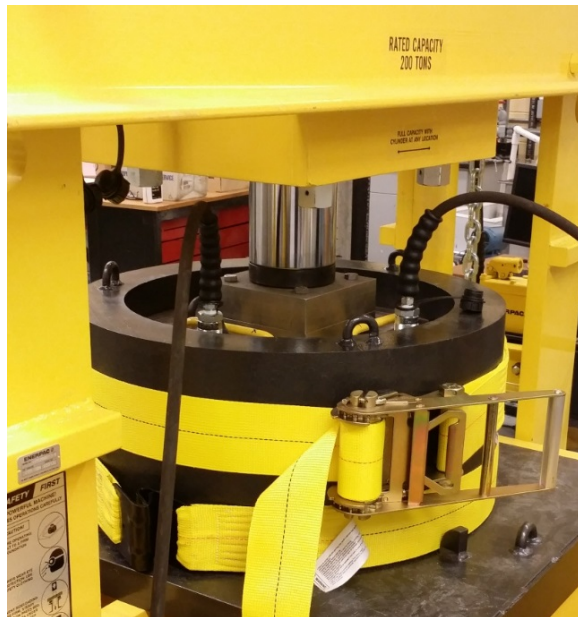
# Thermal fracture propagation

## Liquid nitrogen flow - acrylic specimen

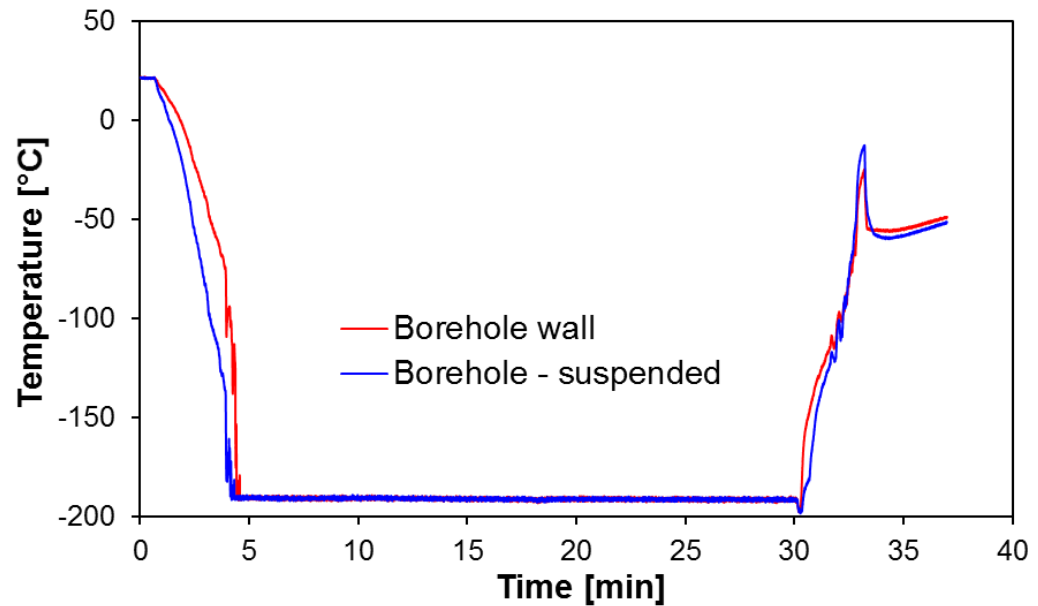


# Triaxial loading

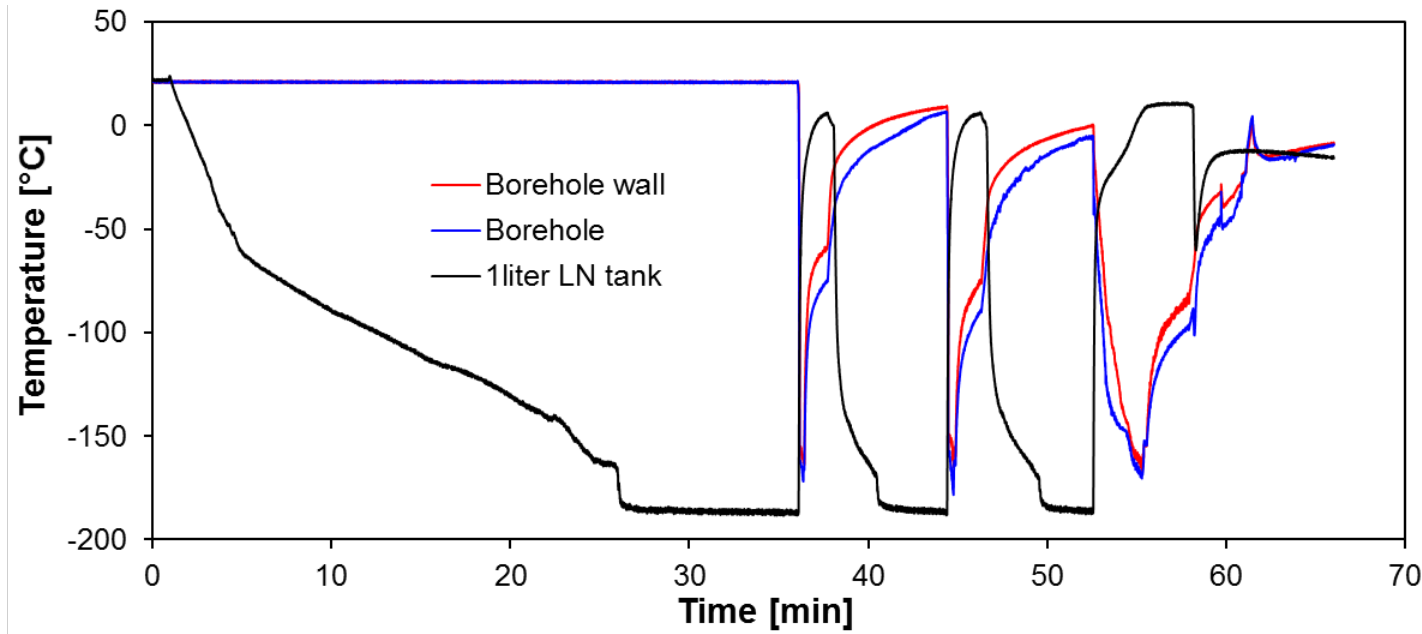
- Simulating in-situ stress
- Loading 20cm cube up to 35 MPa in x & y axes, and 45MPa in z axis,
- Independently control loadings in the three axes.



# Liquid nitrogen flow – temperature in borehole



The higher the flow rate,  
the quicker the temperature drop.

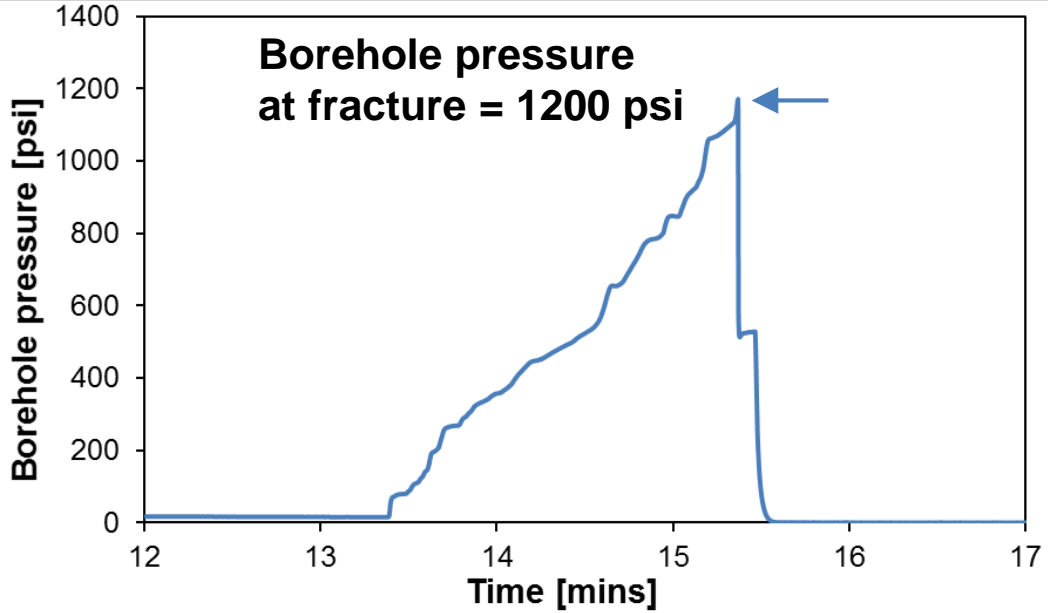




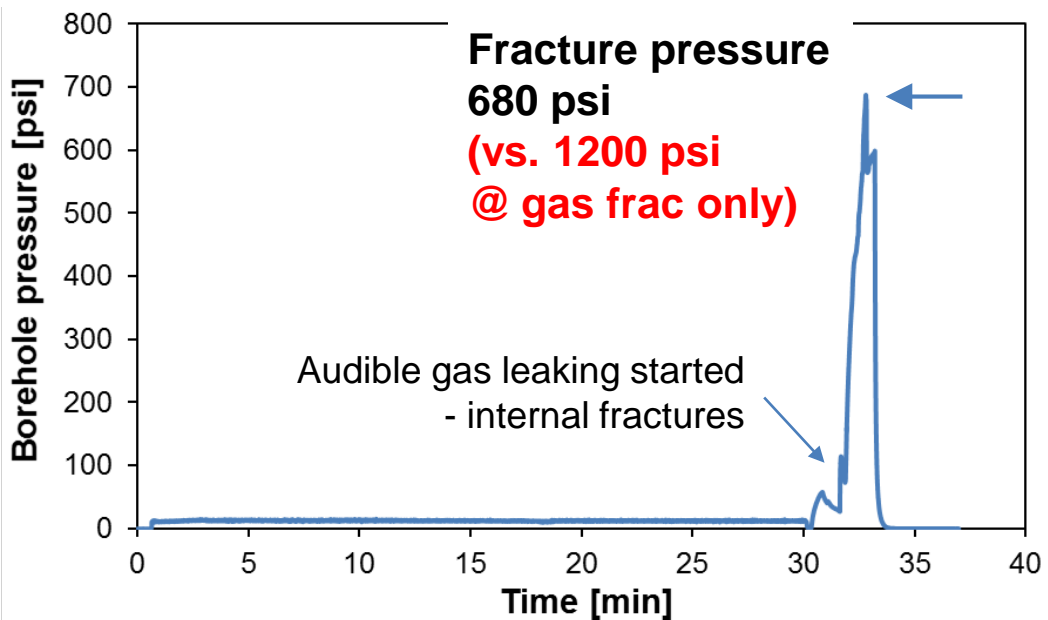
# Breakdown pressure – Comparison

**Untreated**

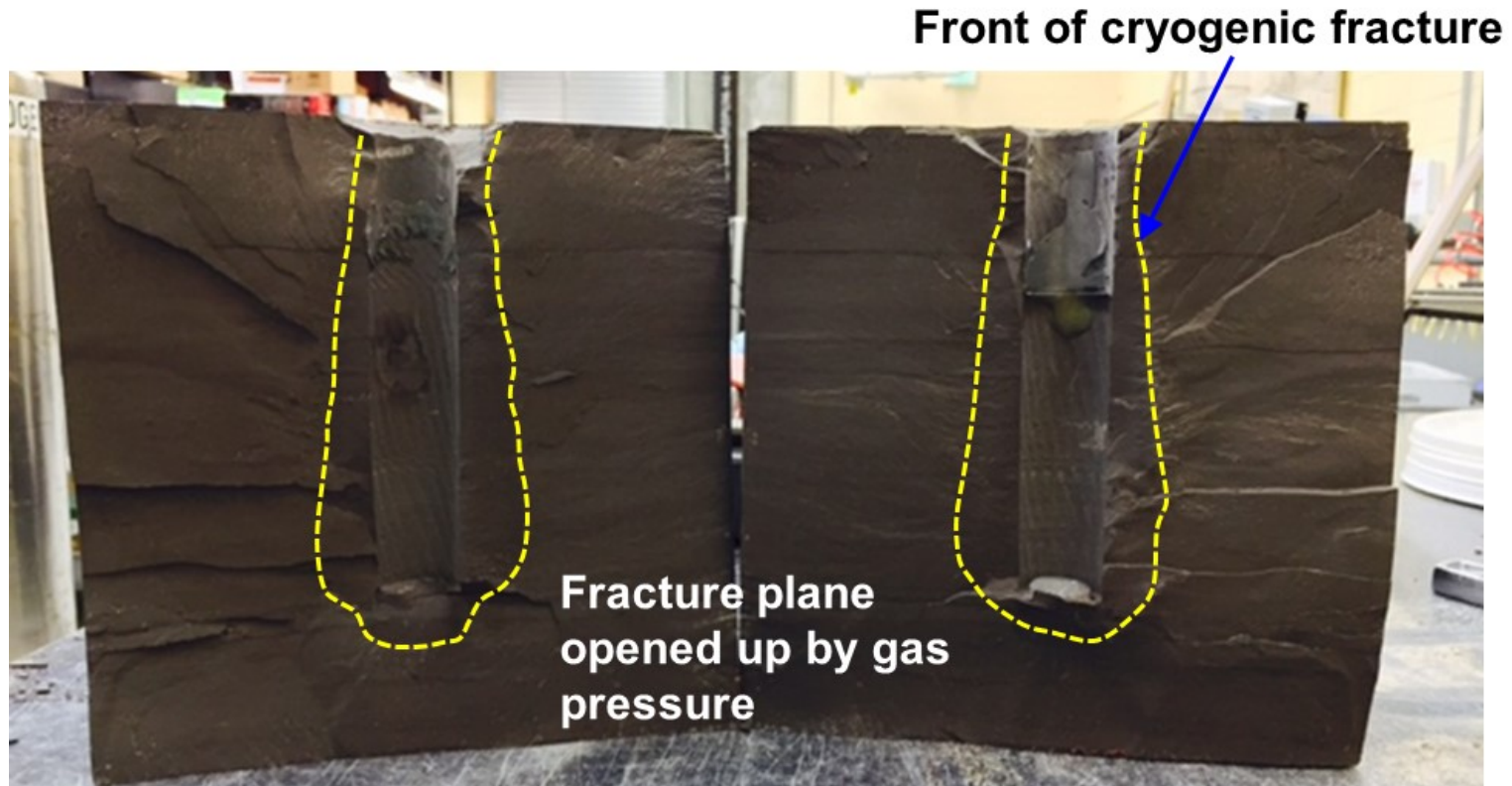
**Confining stress  
x:y:z=500:750:1000 psi**



**After LN flow**



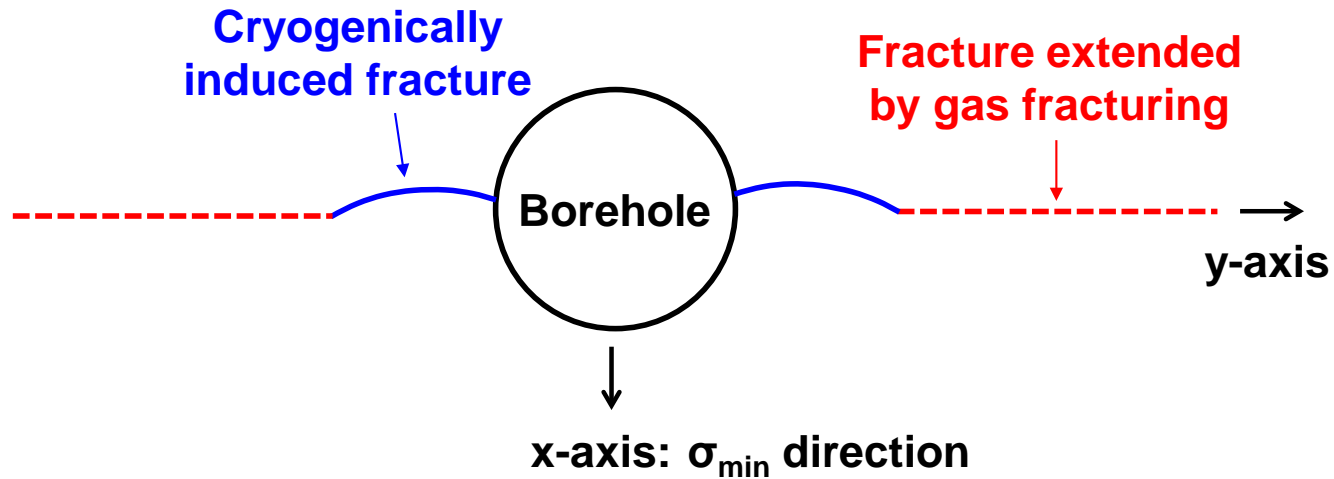
# Thermally induced fractures as “seed fractures” for pressure-induced fracturing



Confining pressure  $z:y:z = 1000:3000:4000$  psi

Cha et al. 2017

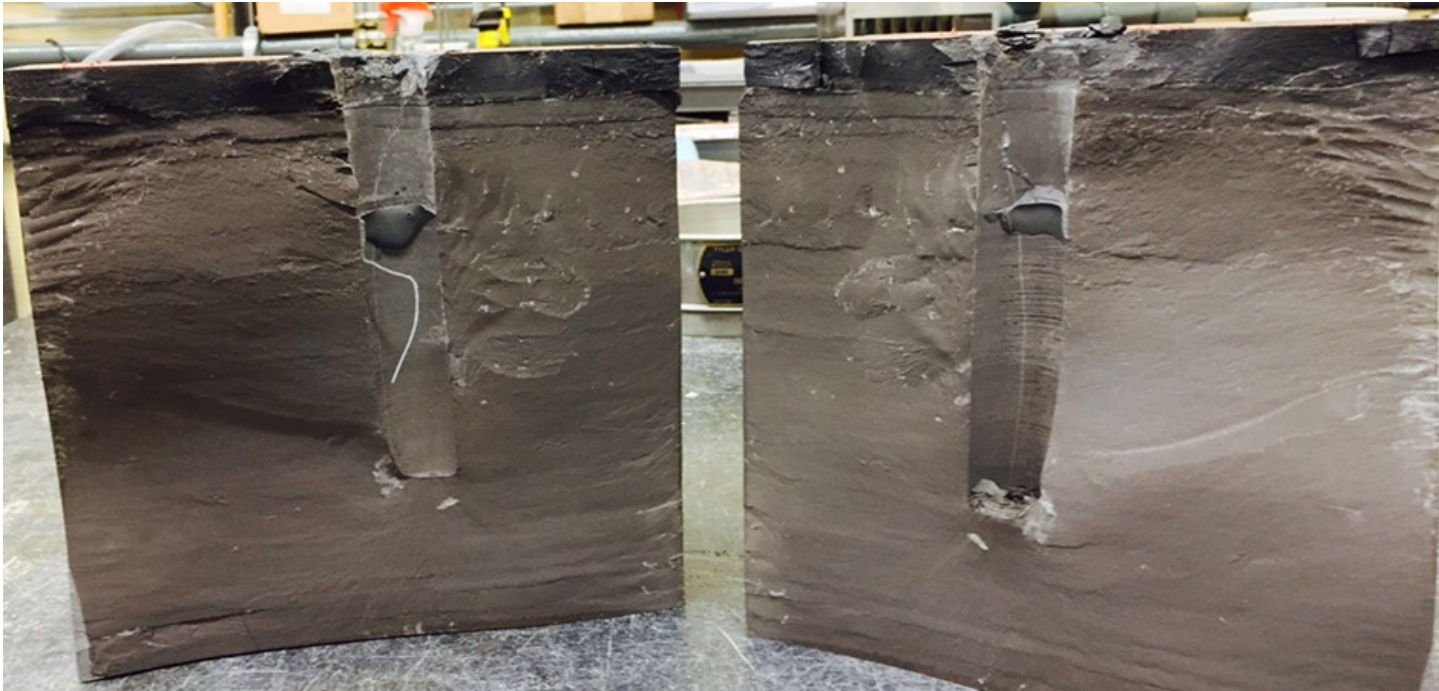
# Depiction of fractures



Slightly curved nature of thermally induced fractures and straighter fractures extended by gas pressure

# Hydraulically induced fractures

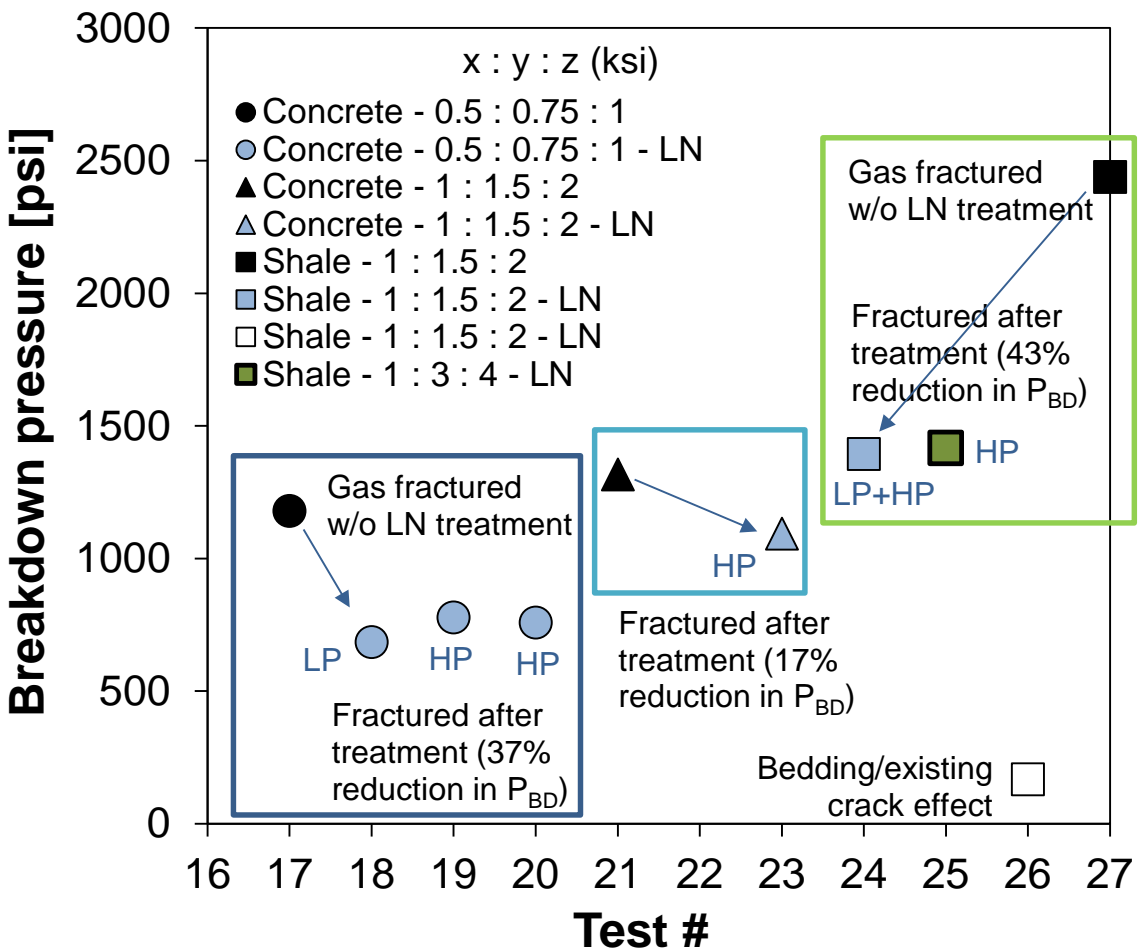
(Gas pressure)



Shale specimen

# Effect of thermal stimulations (liquid nitrogen)

Thermal treatment decreases breakdown pressure



# Conclusions and implications

- Thermally induced fractures and hydraulic fracture have different morphologies in well environment.
  - Common: initiated from the borehole surfaces and propagated into specimen (reservoir)
  - Non-pressurized thermal flow create dense “seed fractures”.
  - Vertical fractures (longitudinal contraction) and horizontal fractures (circumferential contraction). They interact and become complex.
- Thermally induced fractures are limited to near wellbore. However, higher fracture density (smaller spacing between fractures) enhance permeability of local rock volume near wellbore.
- Subsequent pressure-based fracturing will extend from a few of those created the thermal “seed” fractures.
- Thermal fracturing lowers the breakdown pressure level (of hydraulic fracturing).

# Conclusions and implications (2)

- Thermal shock and thermal fracturing is maximized by
  - Continuous fluid flow through wellbore (Stagnant fluid become equilibrium with environment quite quickly.)
  - Higher flow rate → higher thermal exchange → more thermal fracturing
  - Increasing number of treatment cycles enhance thermal fractures.
- Optimized thermal fracturing procedures may be utilized to maximize its potential (increasing local volume permeability and lowering breakdown pressure), yet pressure-based methods need to follow to induce deep fracture penetration.

# Acknowledgements

