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Thermal stimulation of Annular Shale Barriers for Long-Term Well Integrity

SPE Well Decommissioning & Late Well Life in the Net Zero Era, Aberdeen 5th of June 2024

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WHAT STARTS HERE CHANGES THE WORLD

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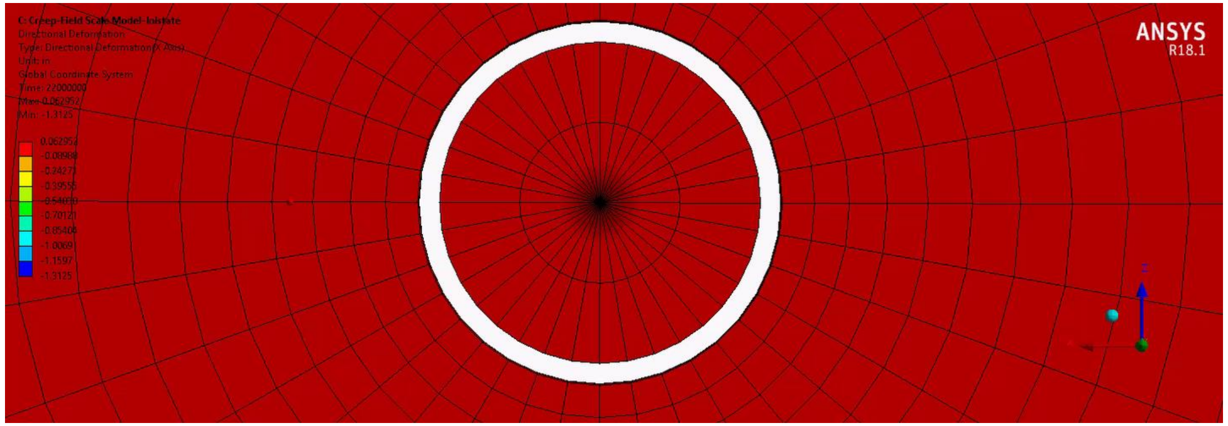
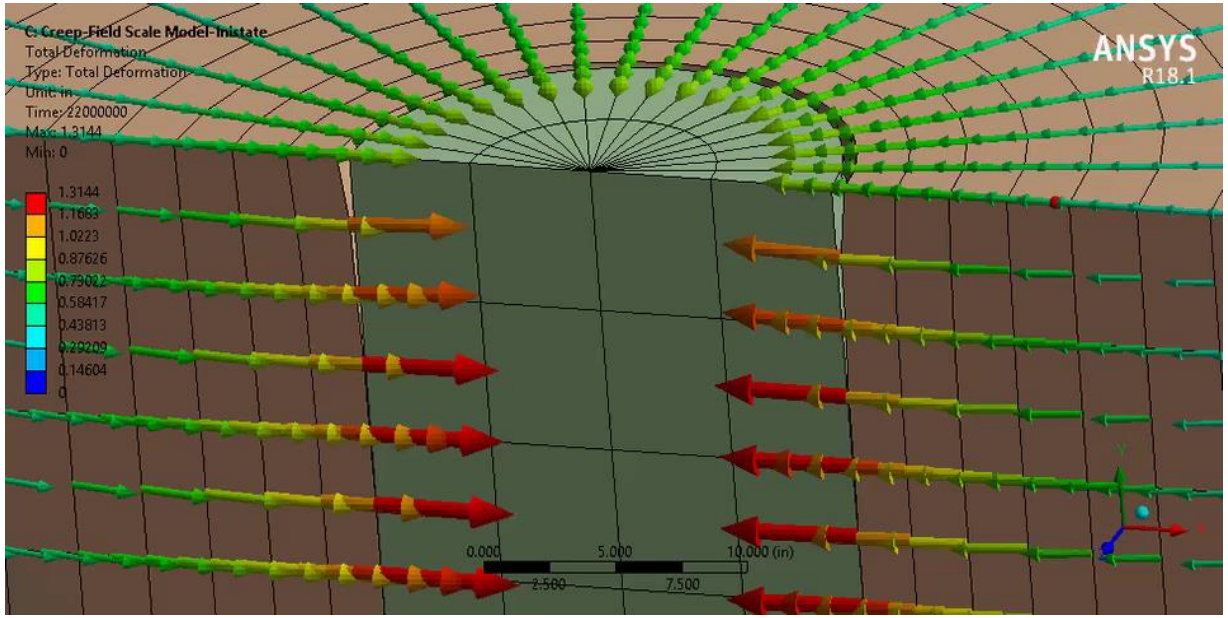
Presentation outline

- Barrier forming shales
- Artificial shale barrier stimulation
- Thermal effects: experimental data
- Thermal effects: literature data
- Safe upper temperature limit
- Conclusions
- Lookahead: SAAB phases II & III
- Acknowledgment





Barrier-Forming Shales

- High total clay content (> 50%).
- Significant free and mixed-layered smectite content (> 10%).
- High porosity (> 25% - 30%).
- High CEC (> 50 meq/100g).
- Low matrix cementation, low quartz and carbonates content (< 30% combined).
- Low strength (UCS and cohesion (S_o) below 1000 psi - 7.0 MPa).
- Low stiffness (lower Young's modulus value).
- Low friction angle (< 15 degrees).
- Low compressional wave velocities (< 2500 m/s - 8,200 ft/s).
- Tendency to cause shale-related borehole instability problems during drilling / tripping

*** Will form barriers naturally, without artificial stimulation**

SAAB Artificial Shale Barrier Stimulation

Three Methods

- **Thermal Stimulation**
  - Elevated temperature accelerates creep rate
  - Elevated temperature generated using a downhole heater / heating mechanism
  - Does not require annular access
- **Pressure Shock**
  - Pressure drops weakens rock, accelerates creep
  - Typically accomplished using packers and low hydrostatic head
  - Requires annular access to expose rock to low pressure
- **Chemical Annular Fluid Change**
  - Accelerates creep through physico-chemical changes (ion-exchange, permeability changes)
  - Requires annular access to expose rock to changes annular fluid chemistry

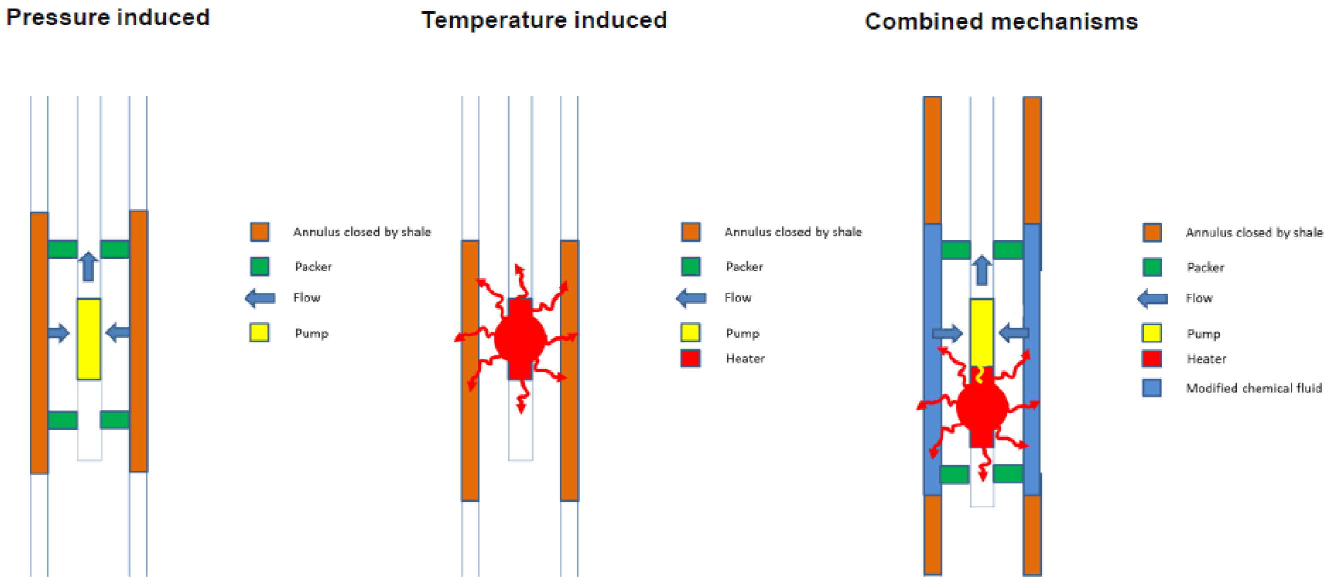
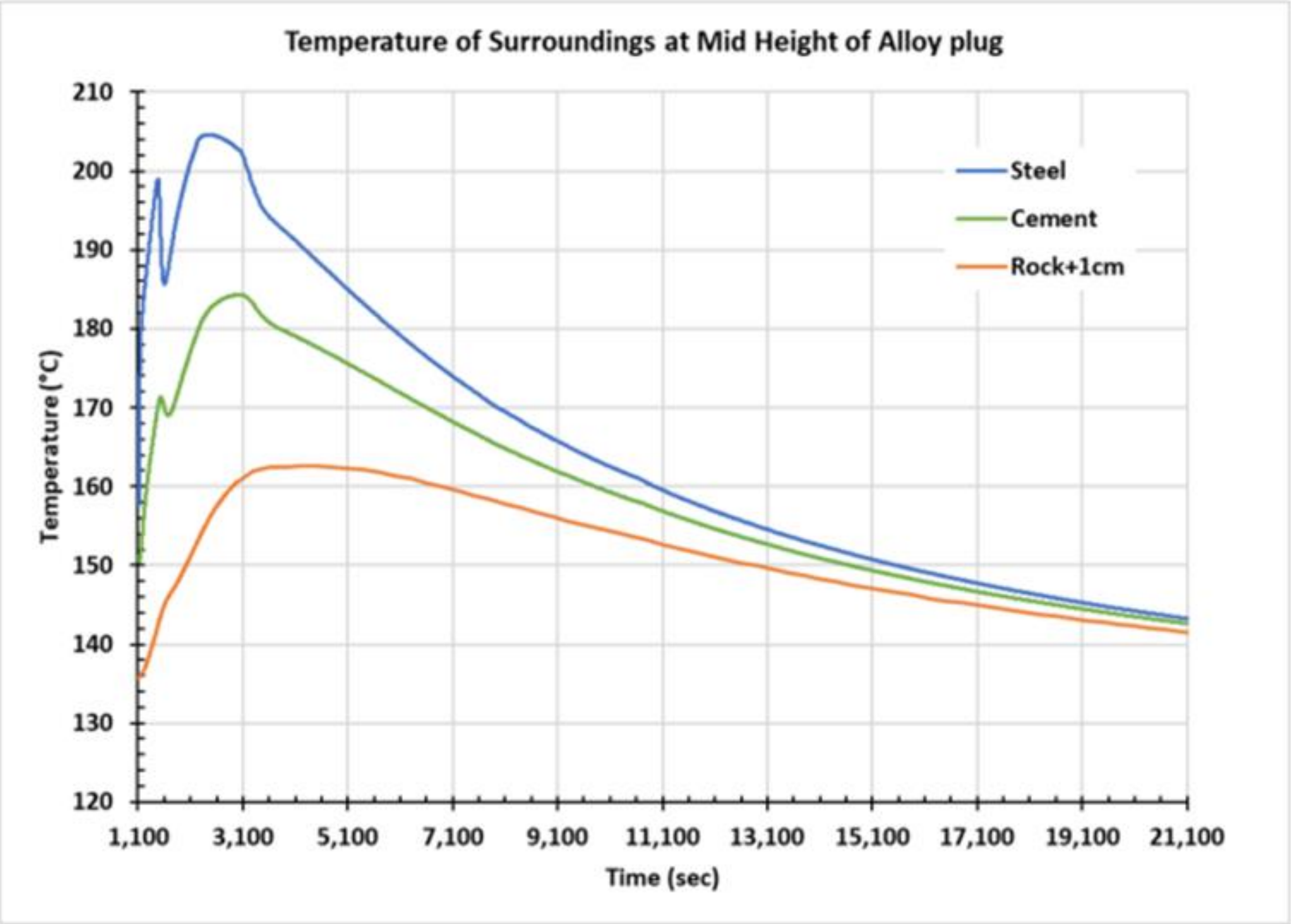


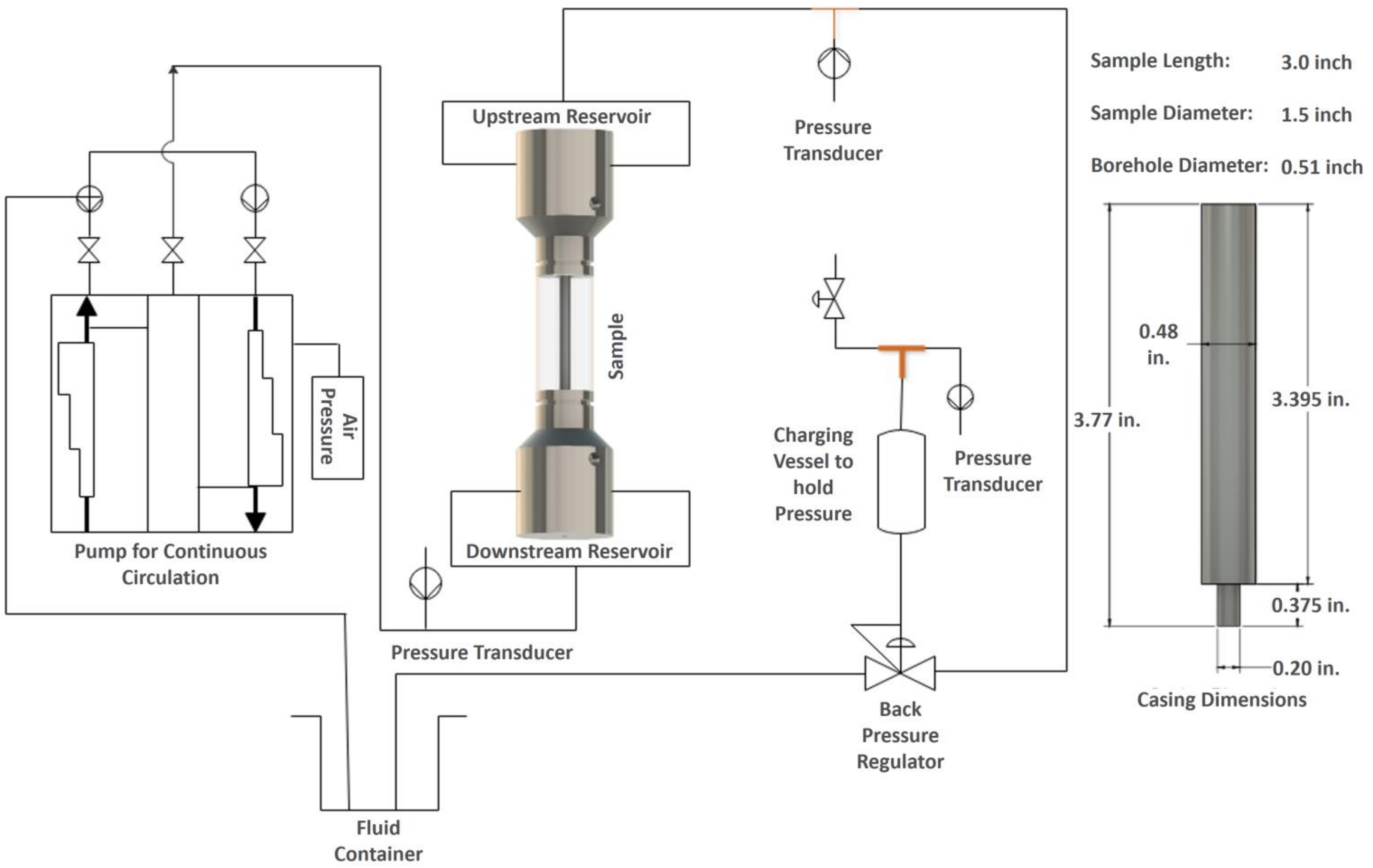
Figure from Kristiansen et al. (2018)

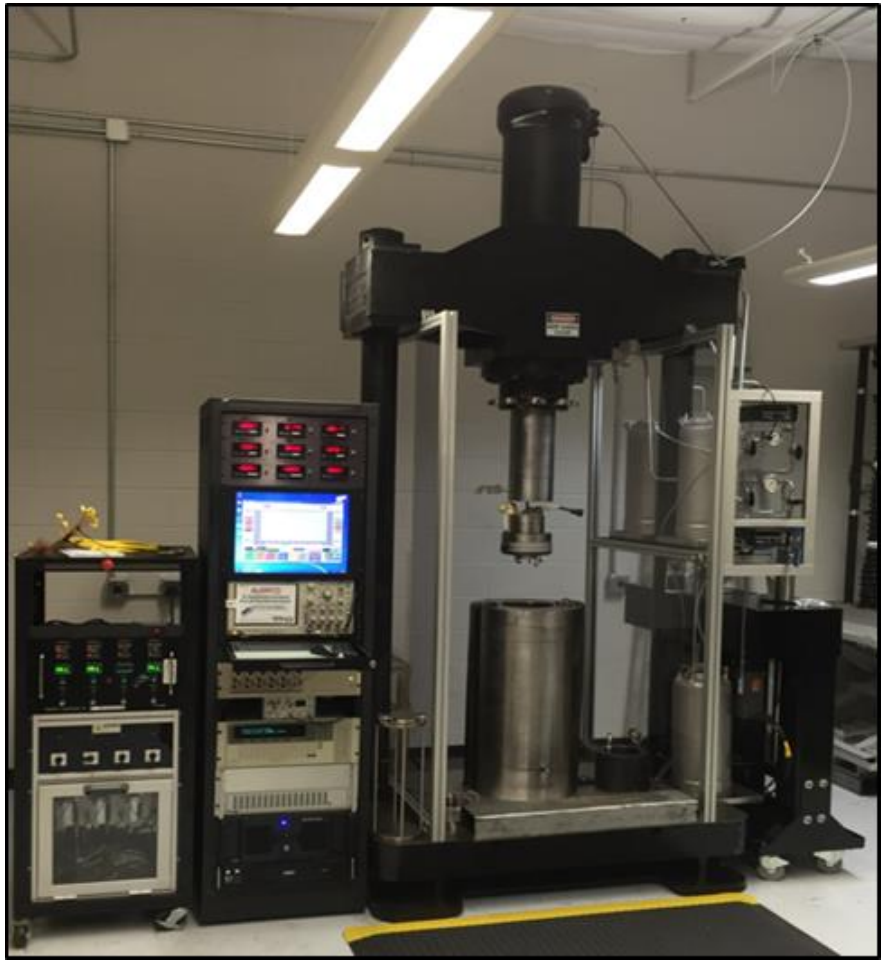
Thermal Stimulation – Heating Profile for Field Heater



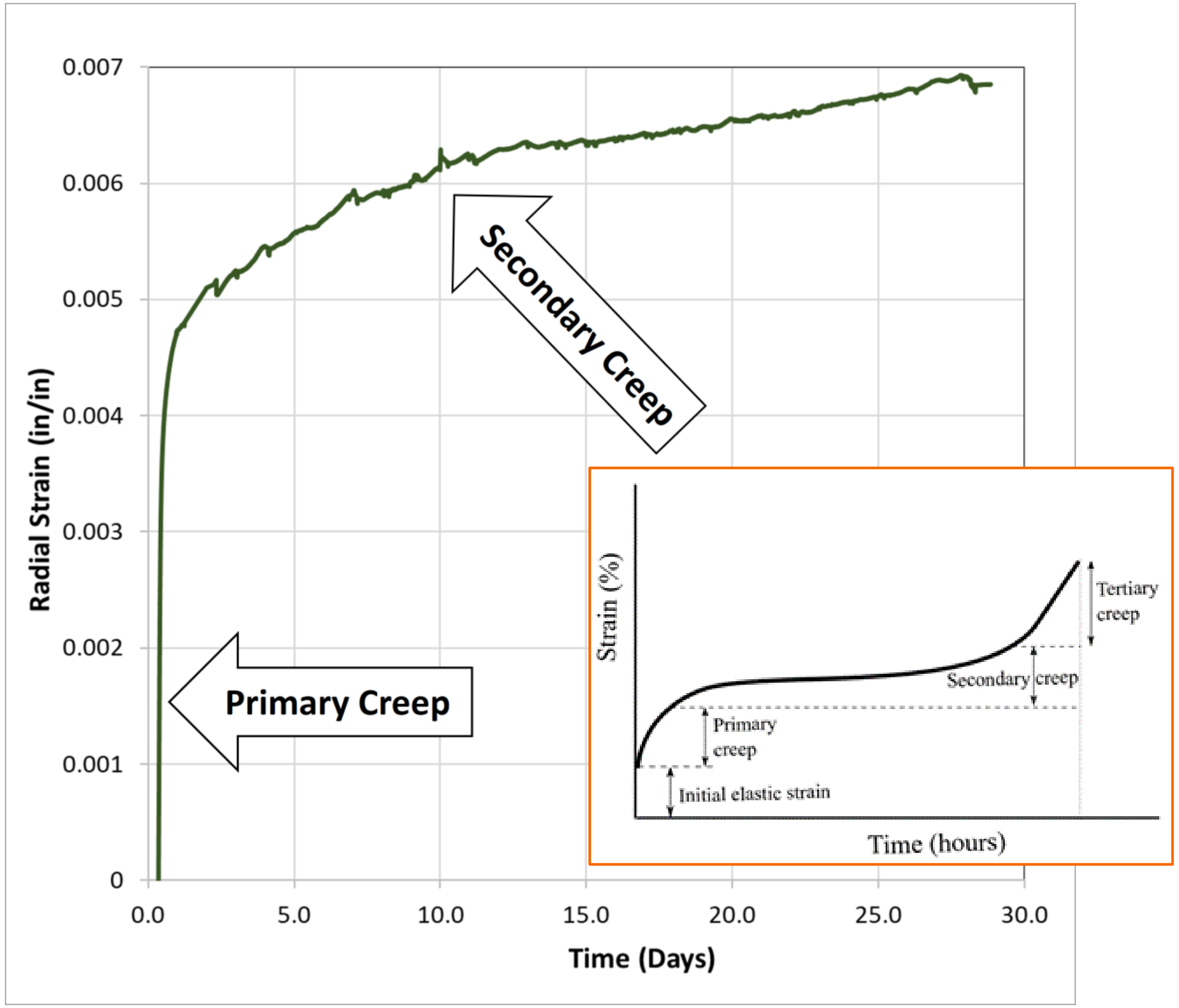
Heating Source:
bismuth alloy candle
(figure courtesy of Isol8)

SAAB Experimental Set-Up

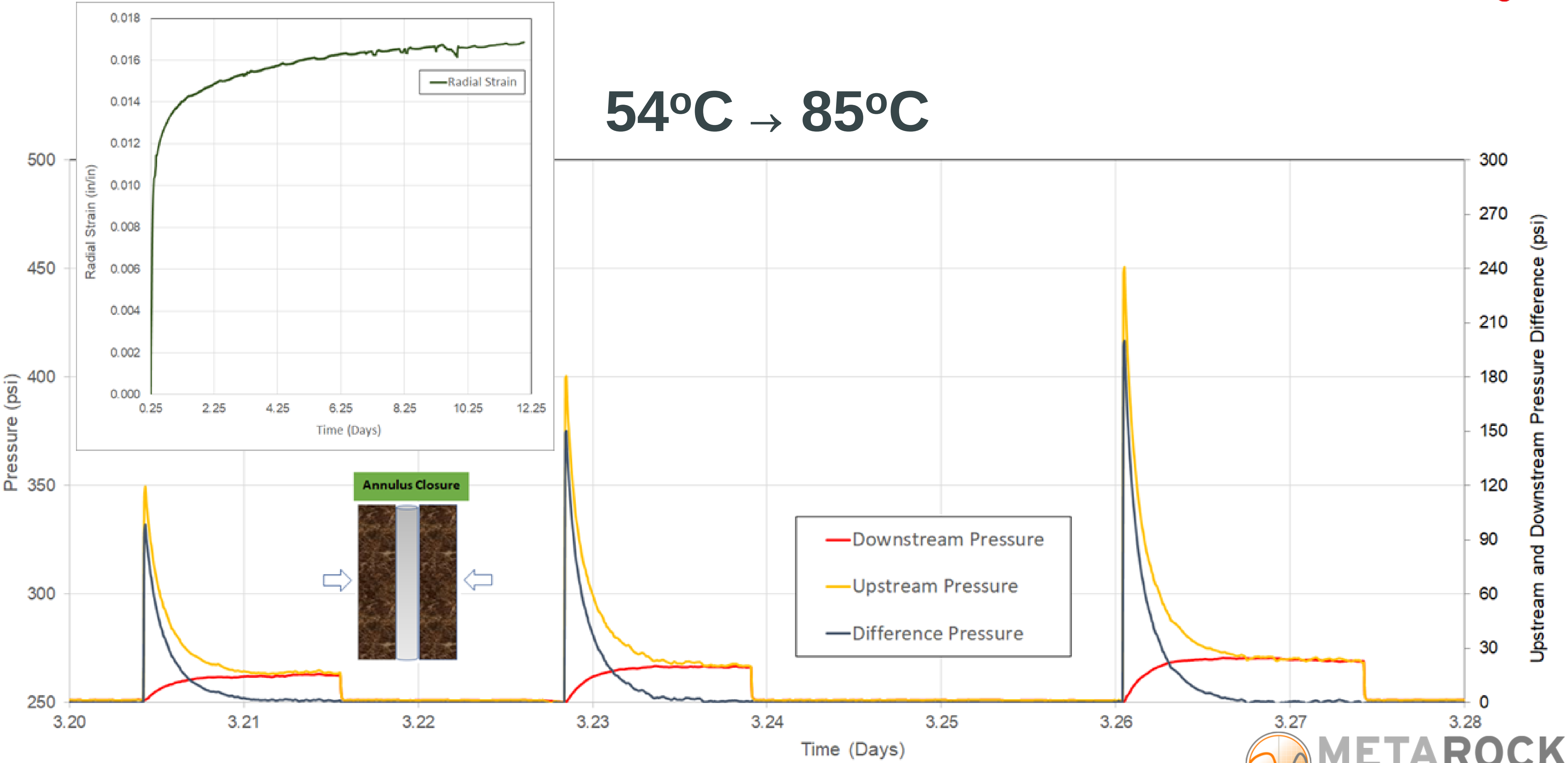




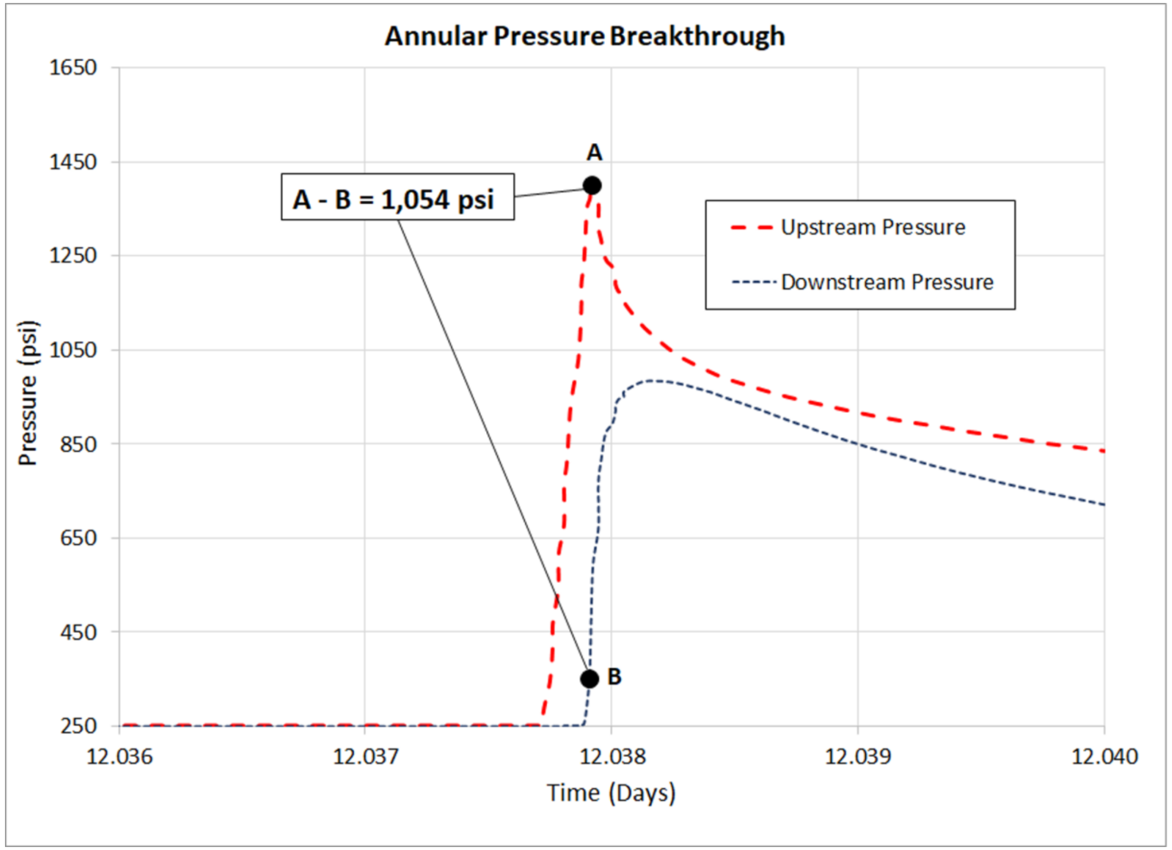
Creep Deformation and Annular Closure

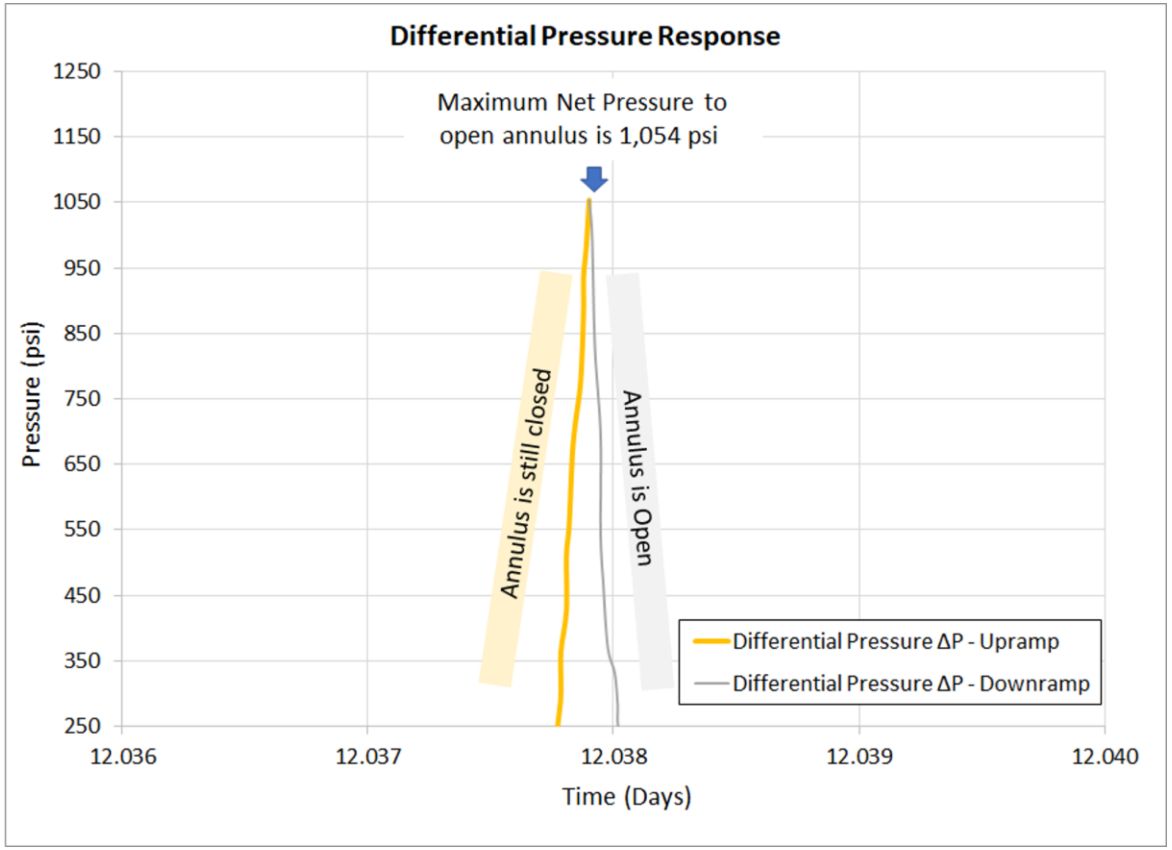


Previous Results: Elevated Temperature Test - 1

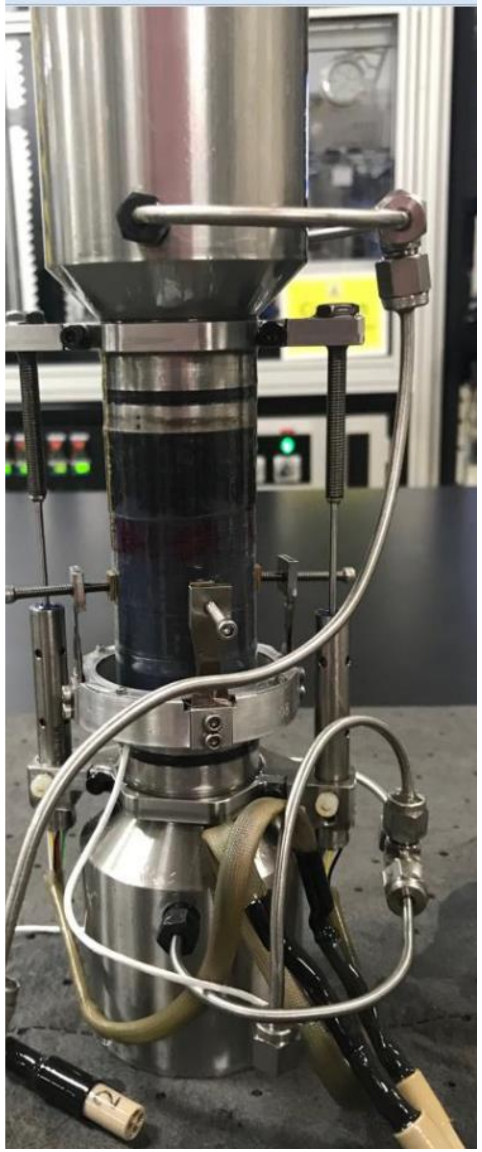


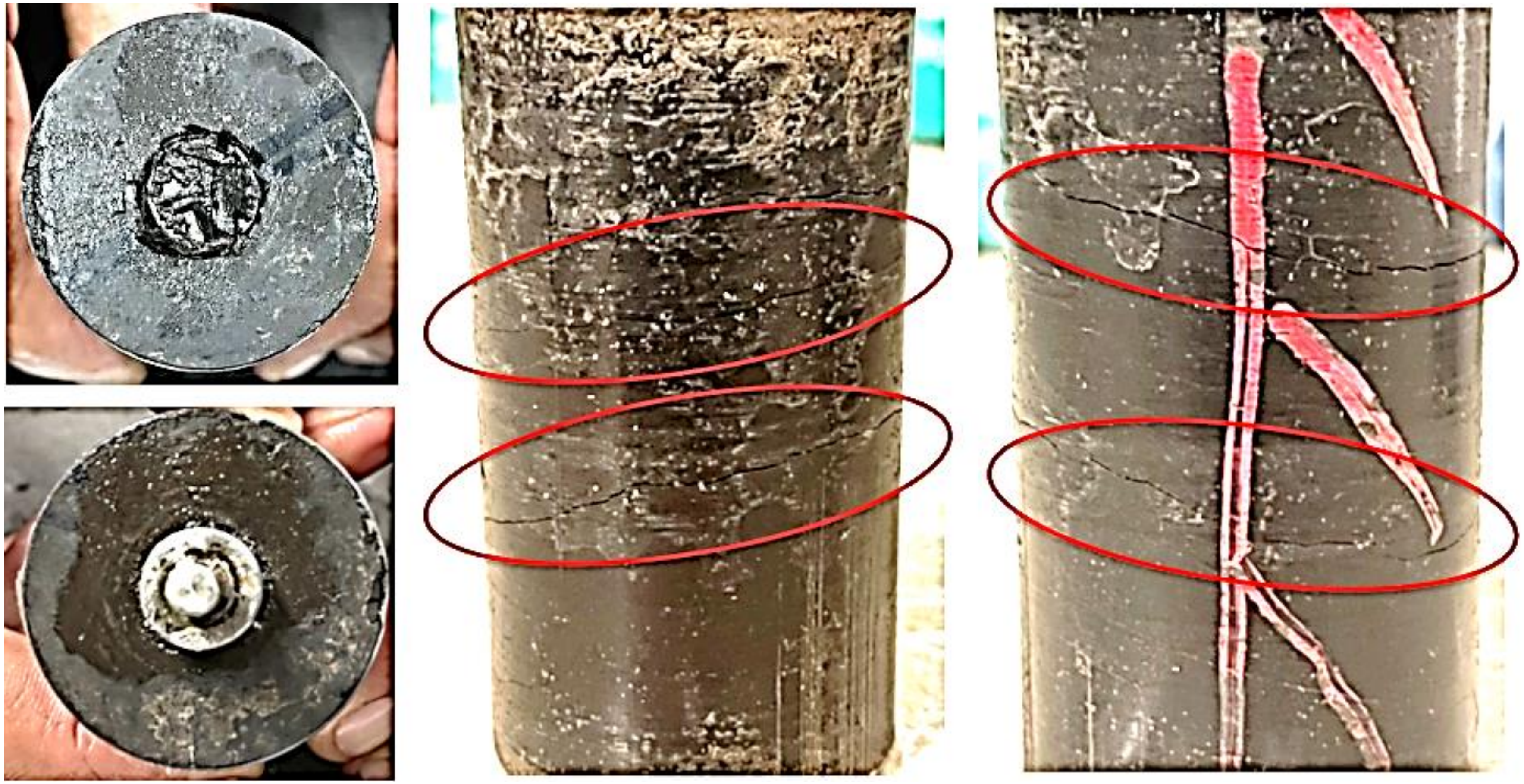
Previous Results: Elevated Temperature Test - 2





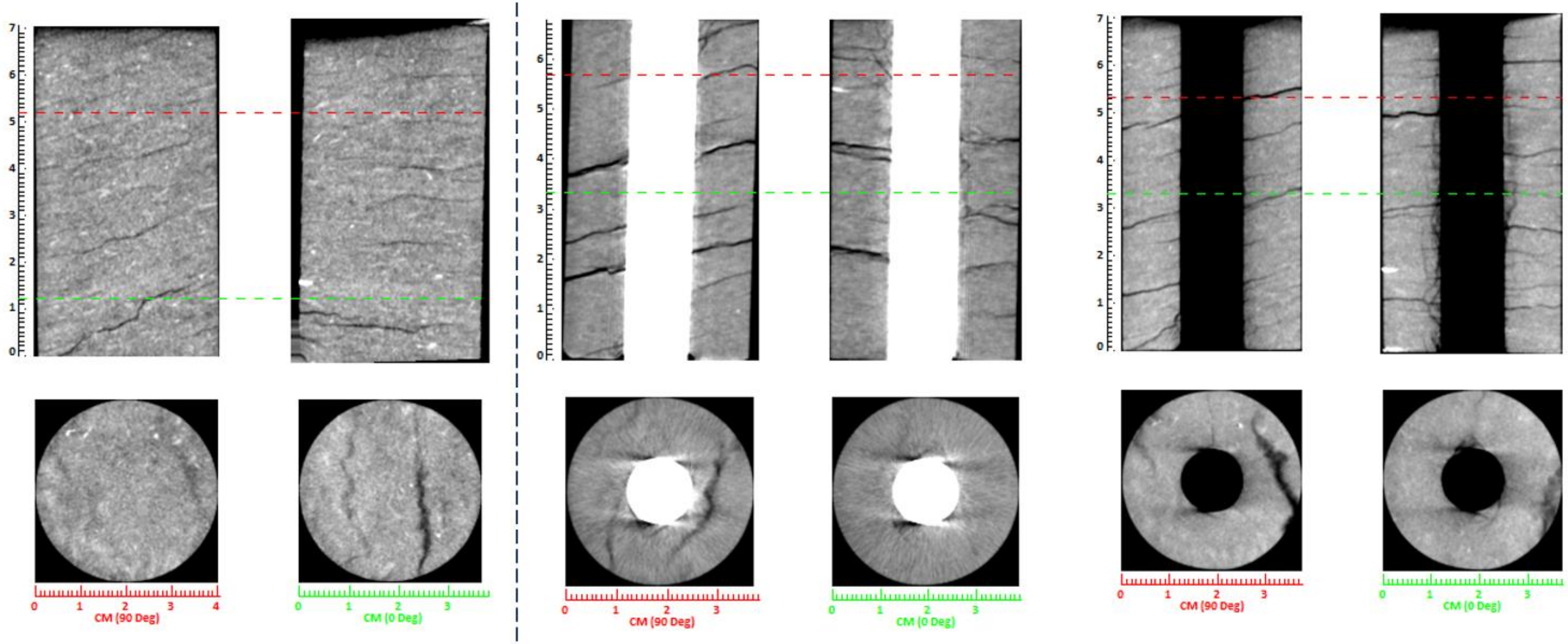
Previous Results: Elevated Temperature Test - 3





Sample showed delamination after unloading, not observed in other tests – effect of elevated temperature!

Previous Results: Elevated Temperature Test - 4

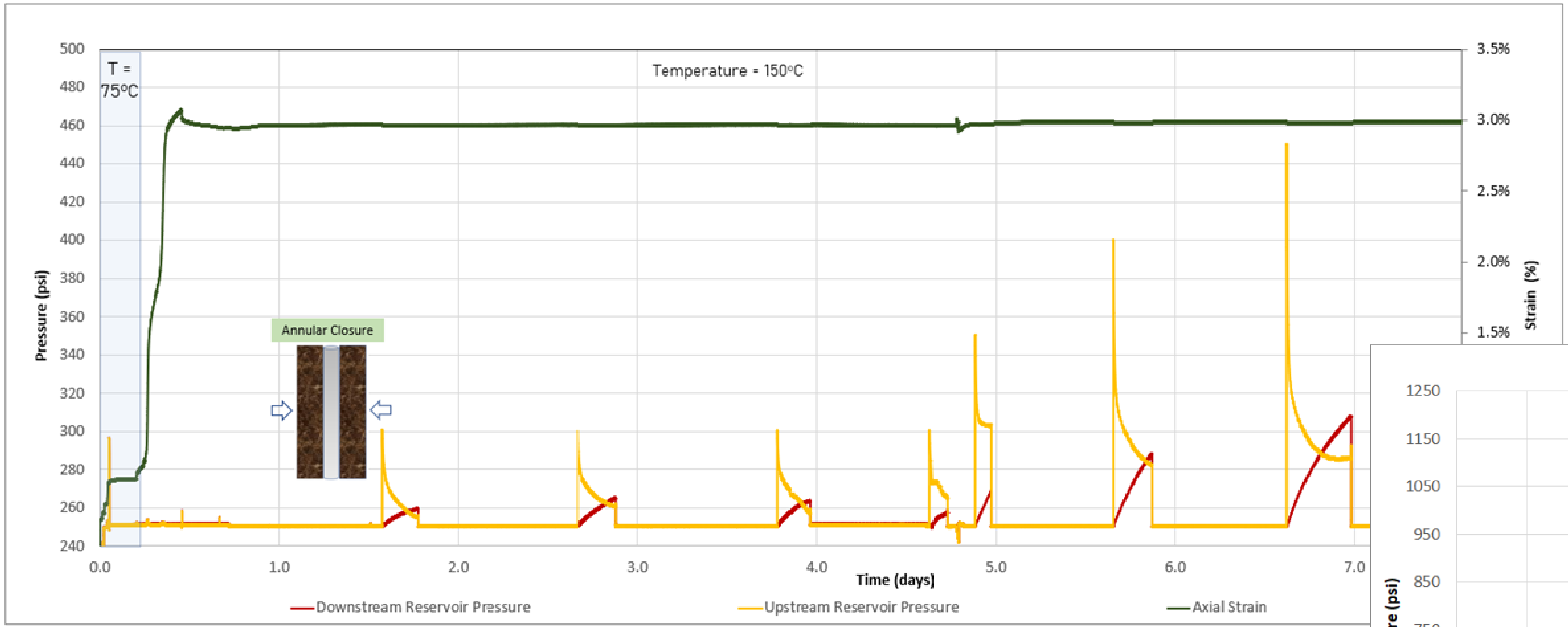


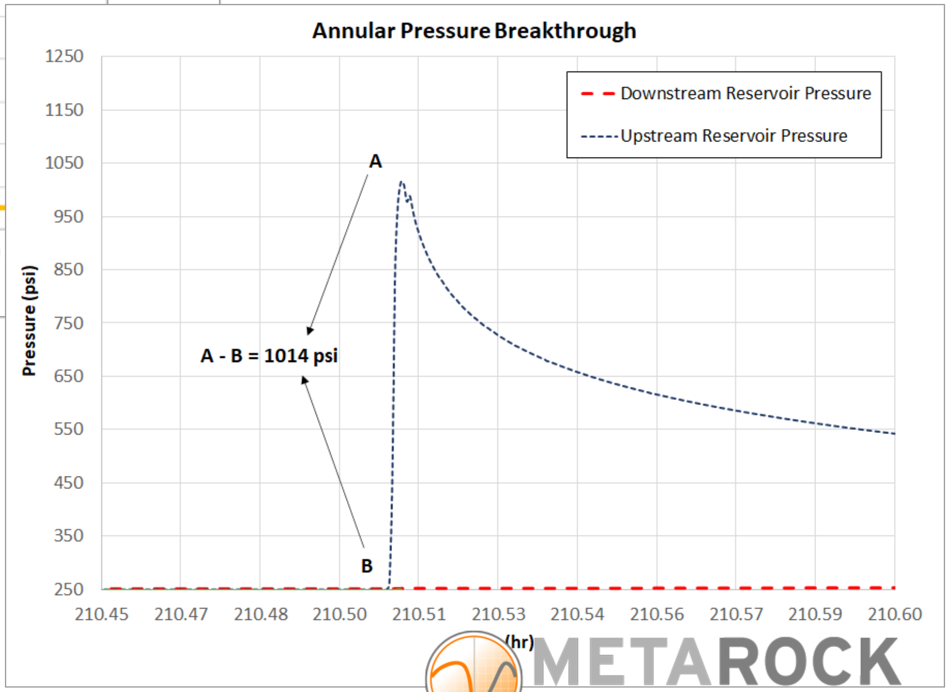
Pre CT- Scan

Post CT- Scan with Rod

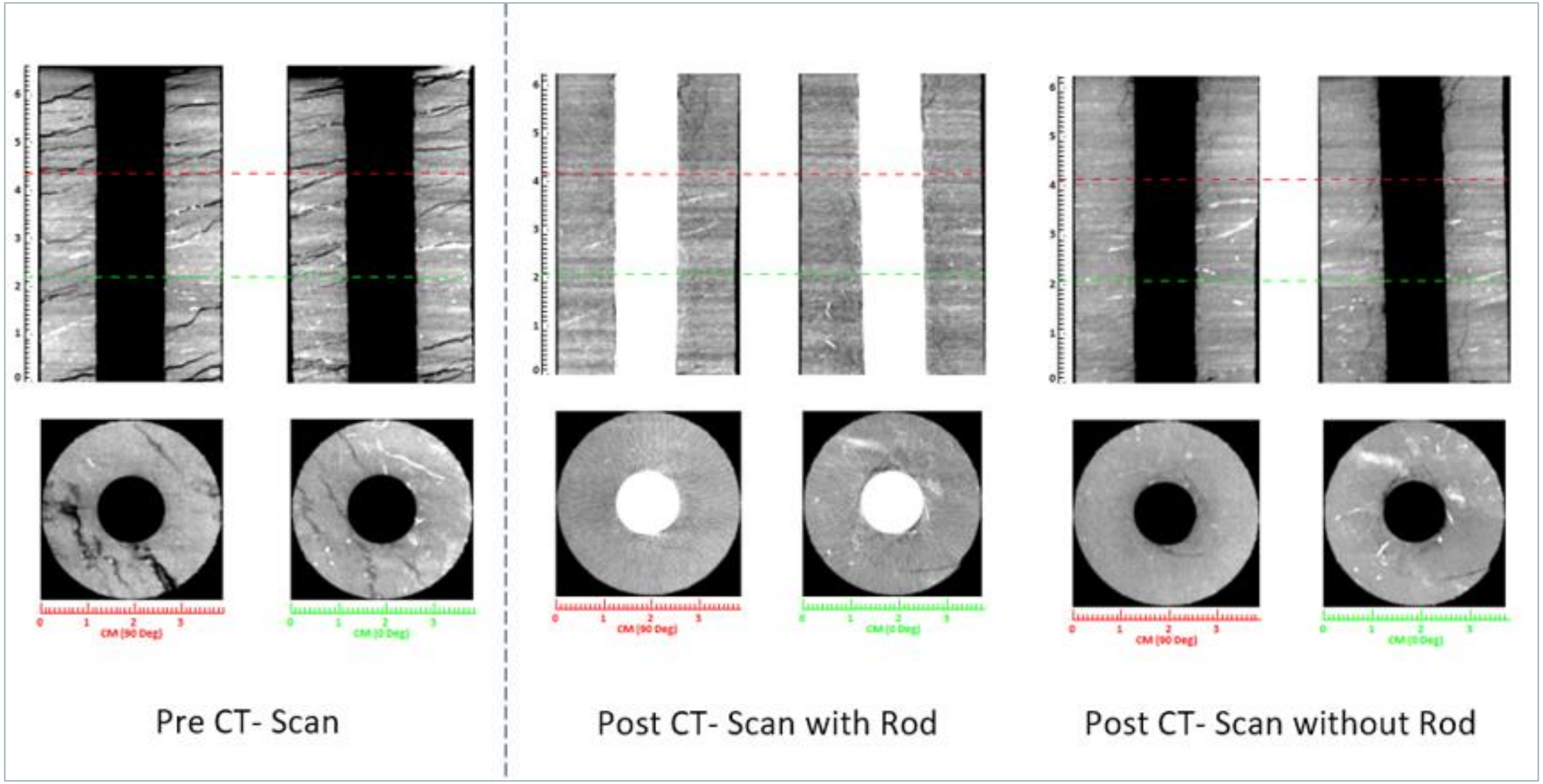
Post CT- Scan without Rod

New Experimental Data – SAAB Testing @ 150^{o}C - 1

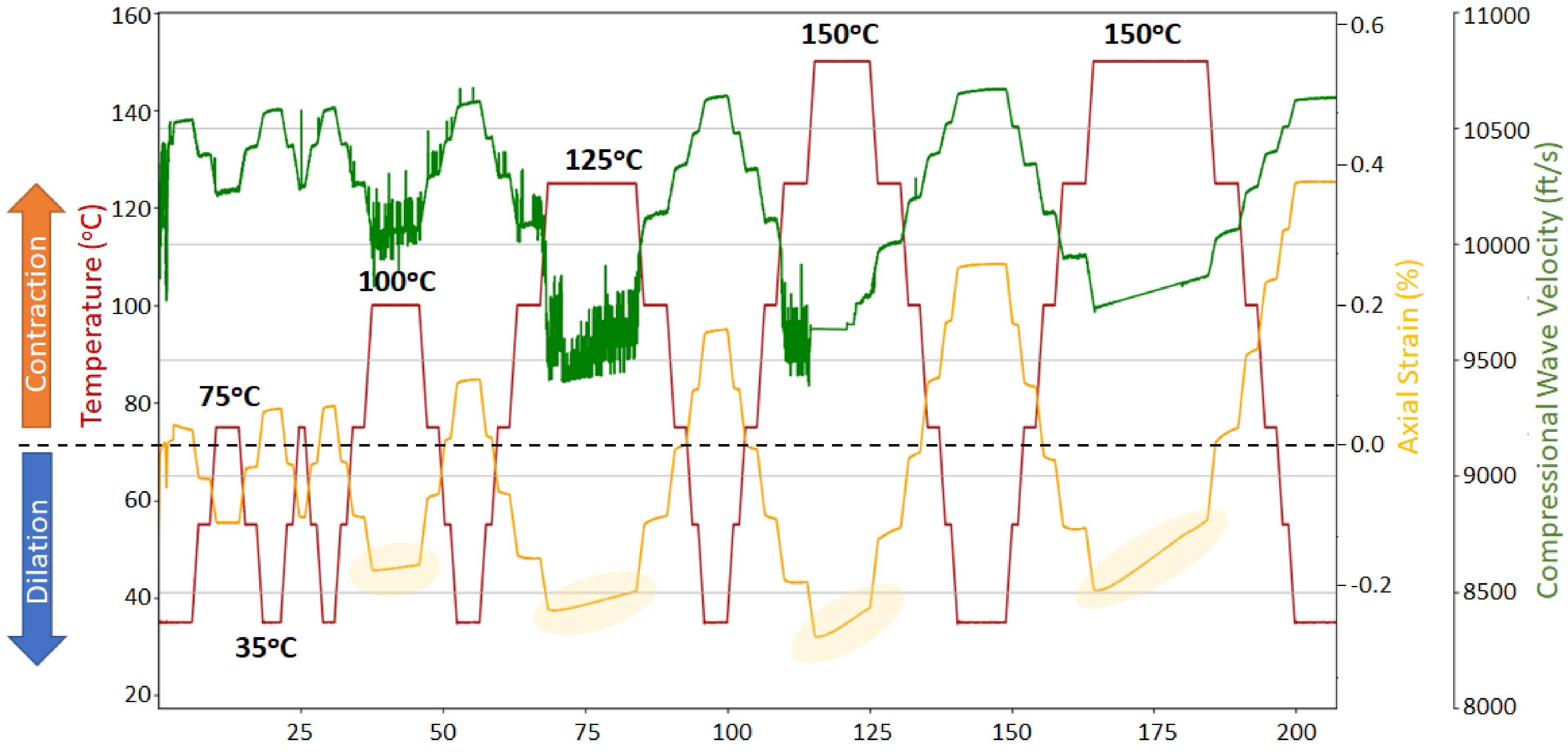




New Experimental Data – SAAB Testing @ 150^oC - 2

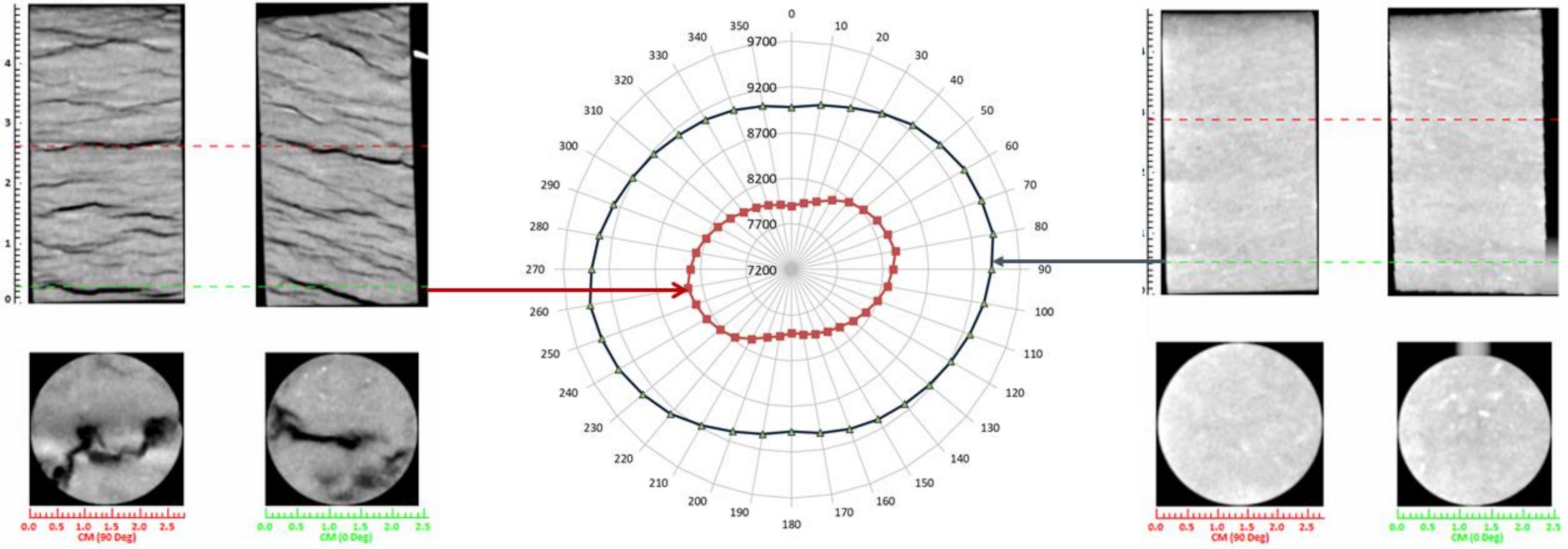


New Experimental Data – Thermal Expansion Testing - 1



"Thermal hardening" was also observed during thermal expansion tests on North Sea Lark and Shetland shales

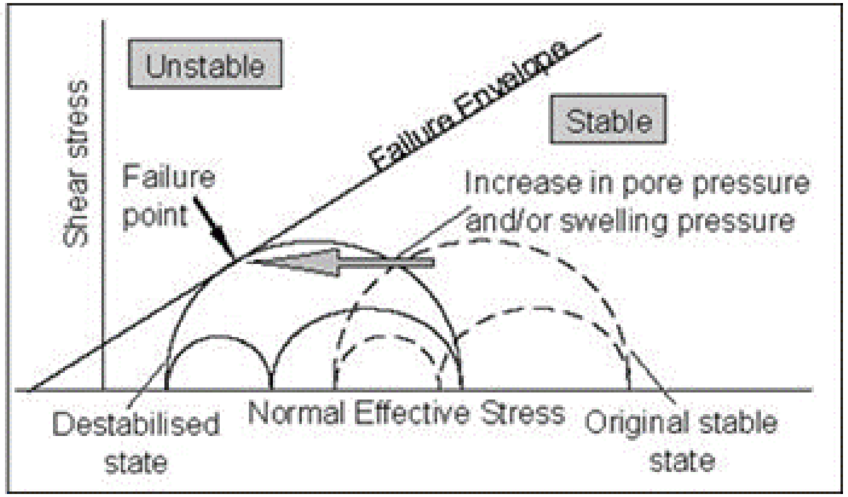
New Experimental Data – Thermal Expansion Testing - 2



Pre-Heated Sample | **Compressional Wave Velocity (ft/s)** | **Post-Heated Sample**

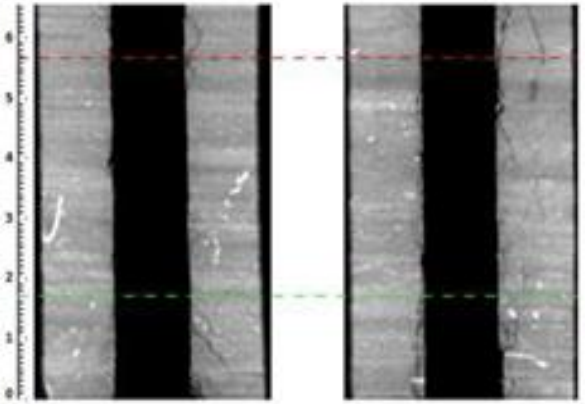
"Thermal hardening" resulted in "healing" of Lark and Shetland core plugs

Discussion



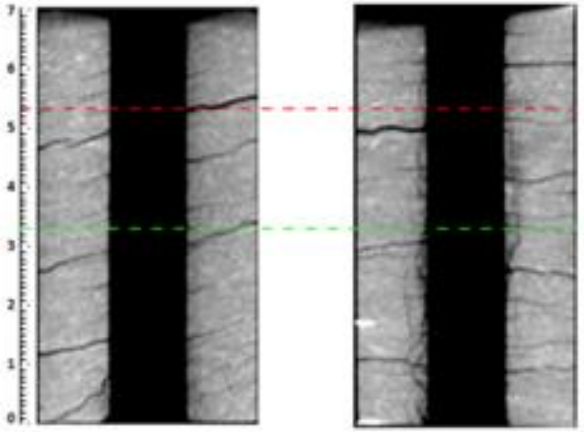
150°C (New SAAB test – this work)

Thermal contraction / shrinkage
Rock plastic deformation
Shale re-healing / crack closure



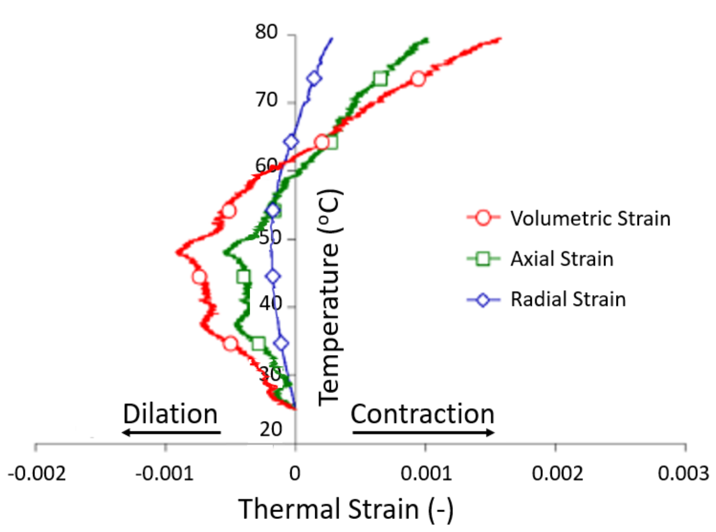
85°C (Old SAAB test – SPE 208782)

Thermal dilation / expansion
Pore-pressure elevation
Effective stress reduction
Shale damage / crack (re-)opening

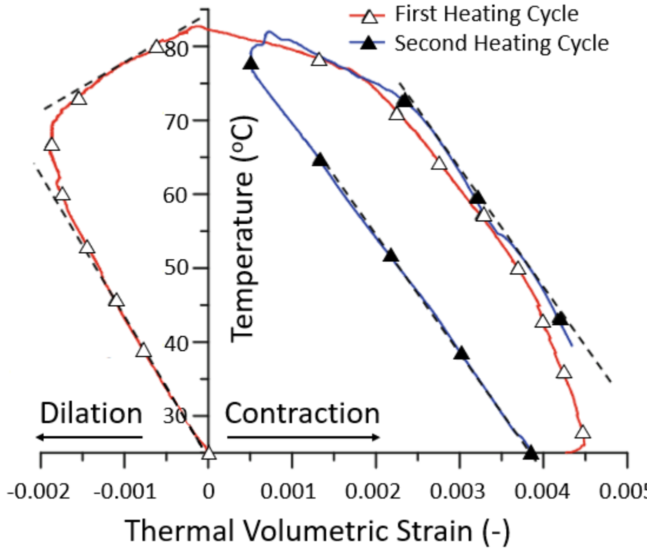


55°C (In-Situ Temperature)

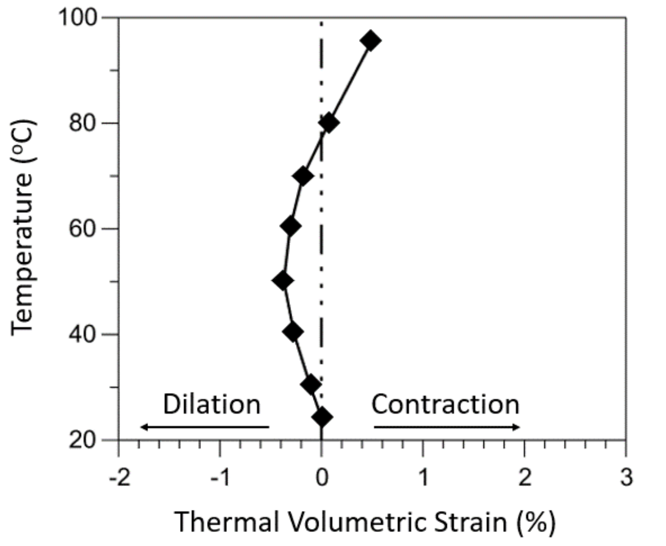
Literature Data for Nuclear Waste Containment Claystones



Data by Belmokhtar et al. (2017), showing strain behavior of COx claystone.



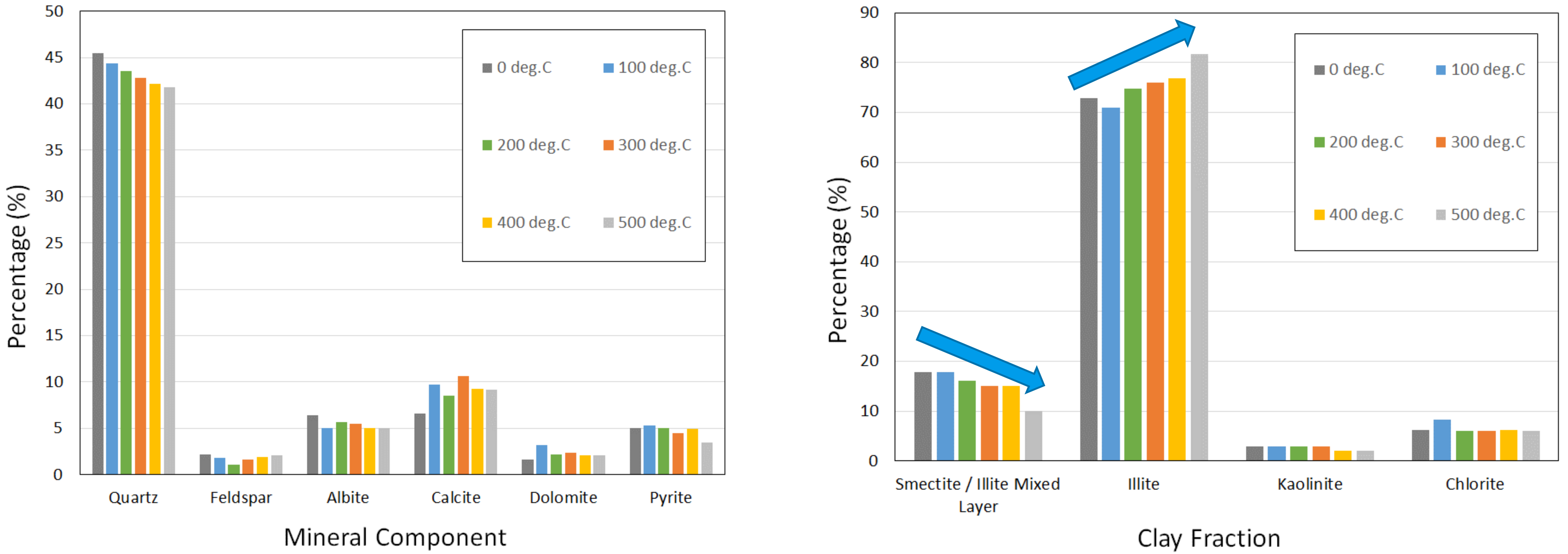
Data by Monfared et al. (2011), showing strain behavior of Opalinus claystone.



Data by Delage et al. (2000), showing strain behavior of Boom Clay.

Literature data on thermal heating of claystones and shales used for nuclear waste containment show a “thermal hardening” effect, with initial thermal expansion upon heating (pore fluid expansion), followed the contraction and thermal consolidation upon prolonged heating

Safe Upper Limit on Heating / Thermal Stimulation



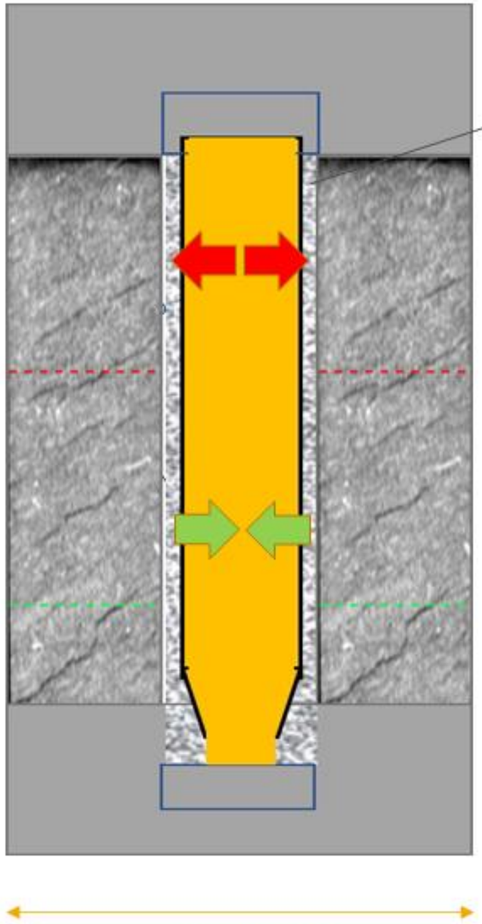
Mineralogical changes in shale from the Lujaping formation treated at different temperatures (100ºC, 200ºC, 300ºC, 400ºC, 500ºC) as reported by Suo et al. (2020). Note the disappearance of mixed layer smectite/illite and the increase of illite with temperature (diagenesis).

Literature data shows safe upper limits to be 300ºC, preferably keeping heating temperature locally below 200ºC

Conclusions

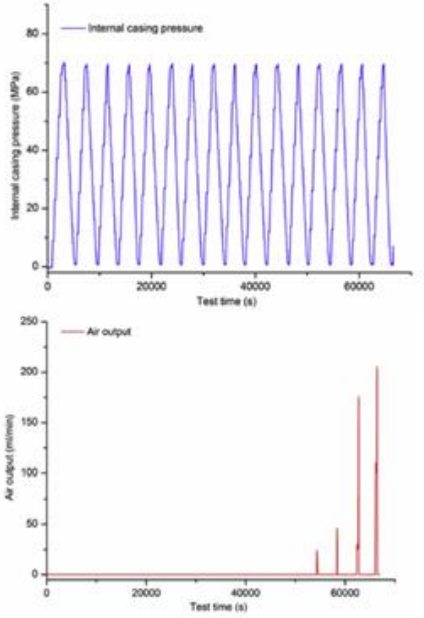
1. Shales such as the North Sea Lark and Shetland Shales show a “Thermal Hardening” effect (increasing temperature leads to pore fluid expansion and dilation, followed by subsequent shale contraction and consolidation). Explains disking cracking caused by effective stress reduction observed for Lark Shale in SAAB tests at 85°C, and its re-healing caused by thermo-plastic consolidation observed at 150°C in the present study.
2. Literature study indicates that changes in shale permeability, porosity, hydration state, and rock strength are all fully reversible up to a threshold temperature in the range of 200°C – 300°C, with 200°C representing a safe, “no-risk” limit and 300°C representing a maximum upper limit.
3. Slow heating of up to a 5°C/hr temperature increase as used in the SAAB tests described here does not negatively affect shales / claystones and, in fact, beneficially accelerates the creeping process that forms annular barriers up to temperatures of 150°C and most likely beyond this temperature (up to a threshold temperature of 200°C – 300°C).
4. It is recommended to test the effect of higher heating rates in the range of 100°C/hr – 200°C/hr temperature increase associated with the field use of downhole heaters. (NOTE: SAAB tests with heating rate as high as 42°C/min temperature increase have now been completed)

SAAB Phase II – Effect of Poor Annular Cementation



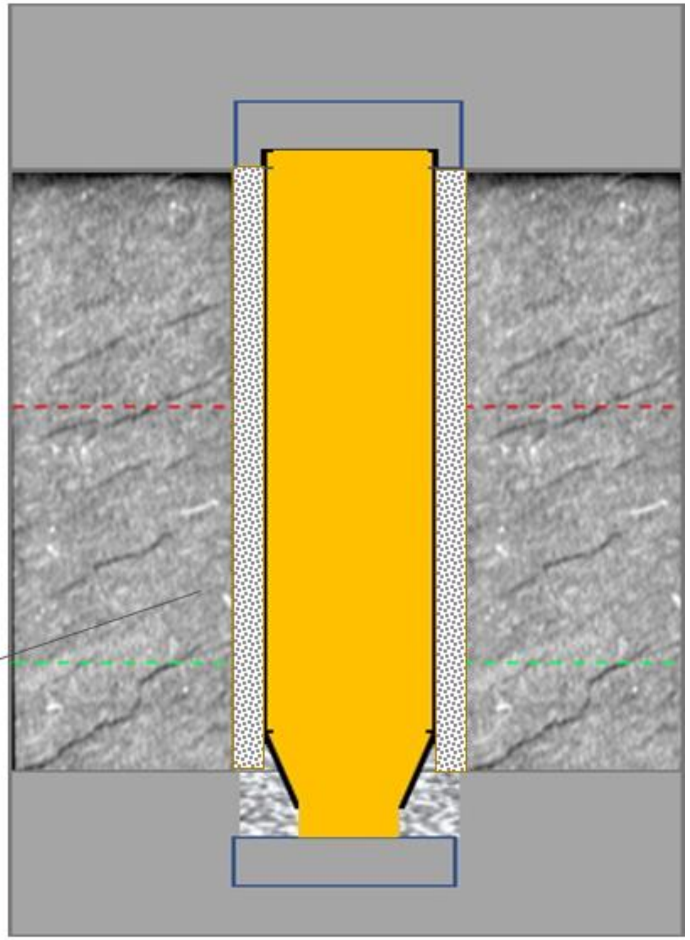
4” sample

Intact cement, subjected to repeated pressure cycles until debonding occurs, subjected to shale creep response

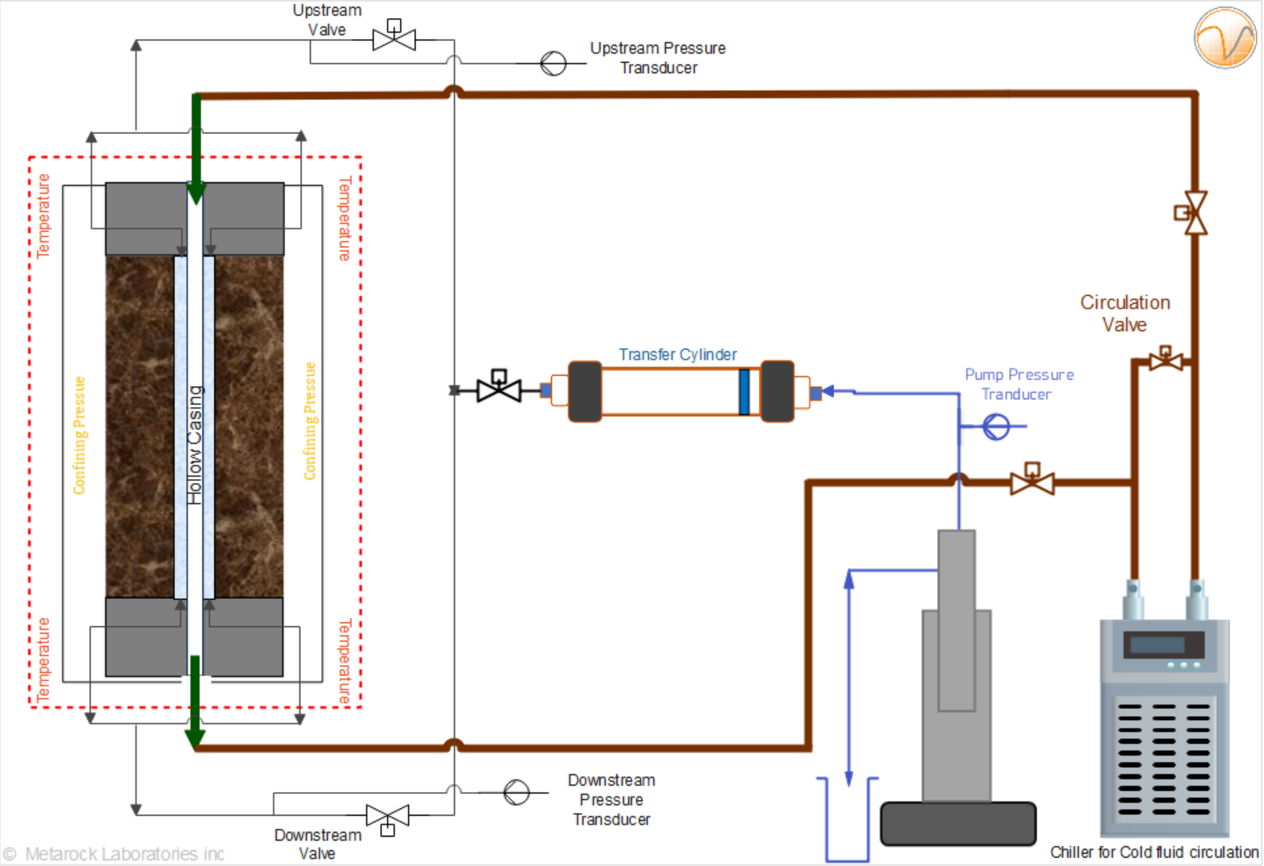


From Zeng et al., 2019

Rubble-ized cement, filling annulus and being subjected to shale creep response



SAAB Phase III – Shale Barrier Integrity in CCS/CCUS Wells



Acknowledgements

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Literature sources quoted in the presentation

- Belmokhtar, M., Delage, P., Ghabezloo, S., & Conil, N. (2017). Thermal Volume Changes and Creep in the Callovo-Oxfordian Claystone. Rock Mechanics and Rock Engineering, 50(9), 2297–2309. https://doi.org/10.1007/s00603-017-1238-7
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- Suo, Y., Chen, Z., & Rahman, S. S. (2020). Changes in Shale Rock Properties and Wave Velocity Anisotropy Induced by Increasing Temperature. Natural Resources Research, 29(6), 4073–4083. https://doi.org/10.1007/s11053-020-09693-5

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