Development of Thermal Breakout Technology for Determining In Situ Stress

Award # DE-FE0031688
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U.S. Department of Energy
National Energy Technology Laboratory
2023 Carbon Management Project Review Meeting
August 28 – September 1, 2023

Agenda

- Project Overview
- Technology Background
- Technical Approach
- Progress and Current Status
- Future Plans
- Summary

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Project Overview

- DOE Funding: $3,132,112
- Cost Share: $818,831
- Project Participants

RESPEC

WISCONSIN
UNIVERSITY OF WISCONSIN–MADISON

Integrity Insitu
INSITU ROCK STRENGTH DATA
INTEGRITYINSITU.COM

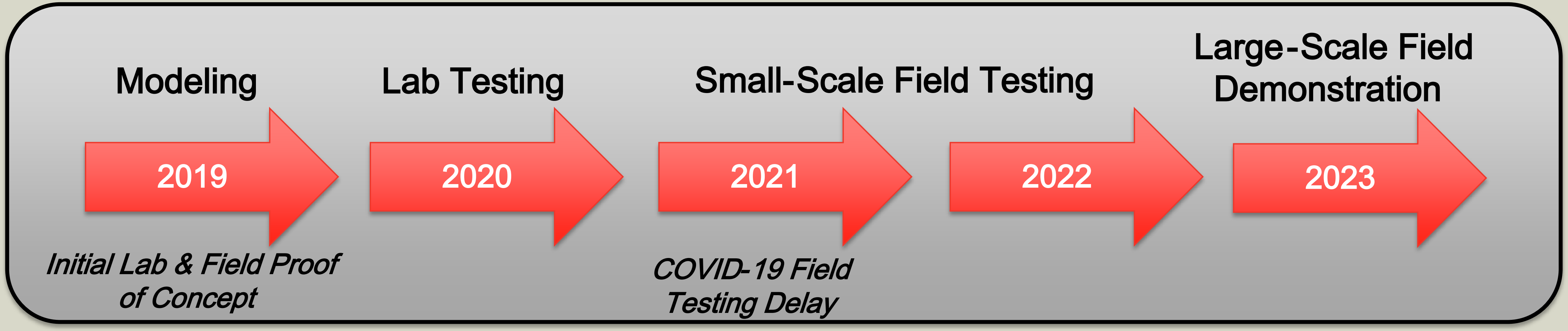
BERKELEY LAB

Sanford Underground Research Facility

Thomas Doe
Daniel Moos

Project Overview

- Use well-established, existing technology to improve the standard methods of in situ stress measurements by including thermally induced borehole breakout technology
- Four primary objectives:
  - Numerical modeling confirms theoretical concept
  - Laboratory testing provides physical validation
  - Small-scale field testing demonstrates functionality
  - Large-scale field testing provides proof-of-concept in deep borehole environment



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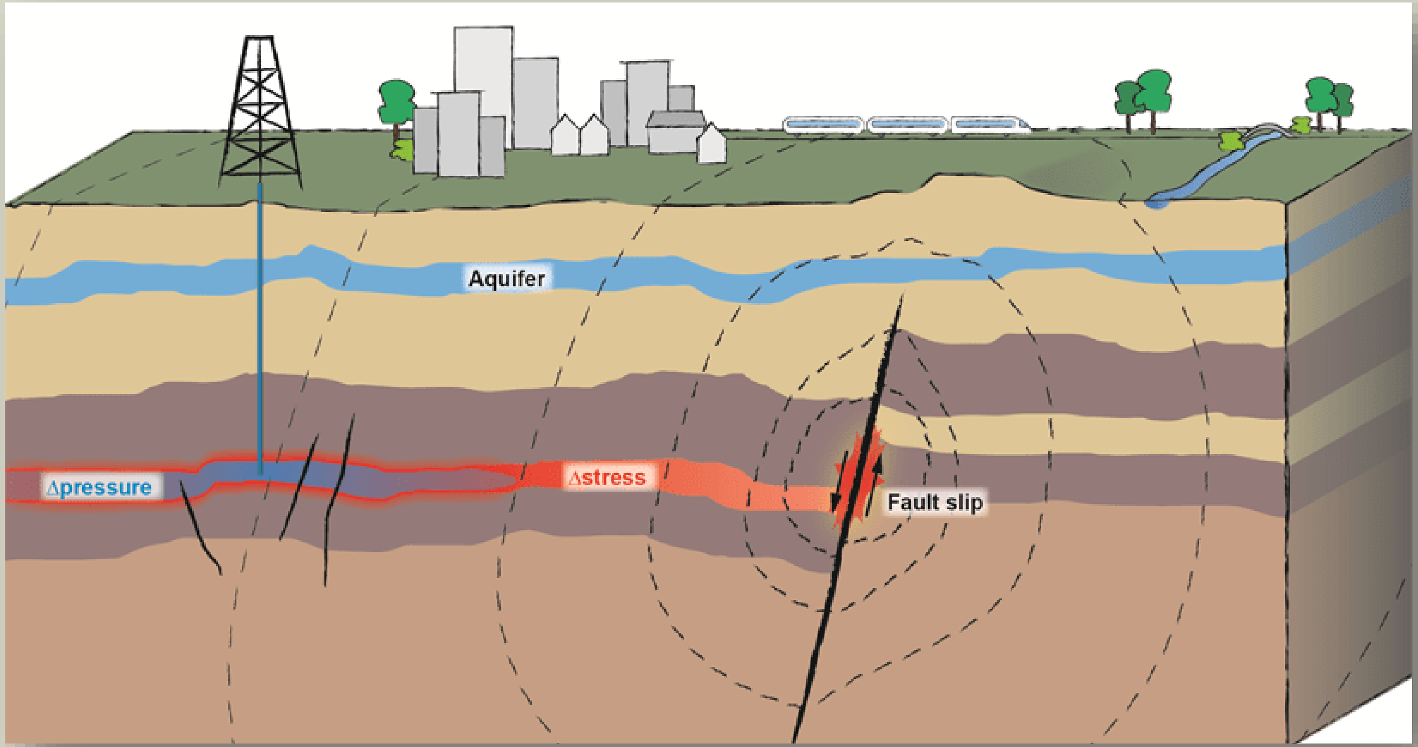
Technology Background

- An accurate measurement of the subsurface in situ stress state is critical for designing successful CO2 injection
  - Understand acceptable injection pressures, volumes, etc
  - Maintain caprock integrity
  - Avoid induced seismicity

- Current in situ stress technology is limited… especially for the maximum horizontal stress



Rutqvist et al. [2016]

Technology Background

- One of RESPEC's past R&D projects (DE-SC0011888) focused on developing a downhole tool for melting rock as a method to seal boreholes
- We were able to successfully melt rock, but the induced heat caused fractures to form
- These fractures appeared to be related to the stress acting on the borehole
- These observations of thermally-induced fractures spurred the idea for a new in situ stress measurement method suitable for CCS

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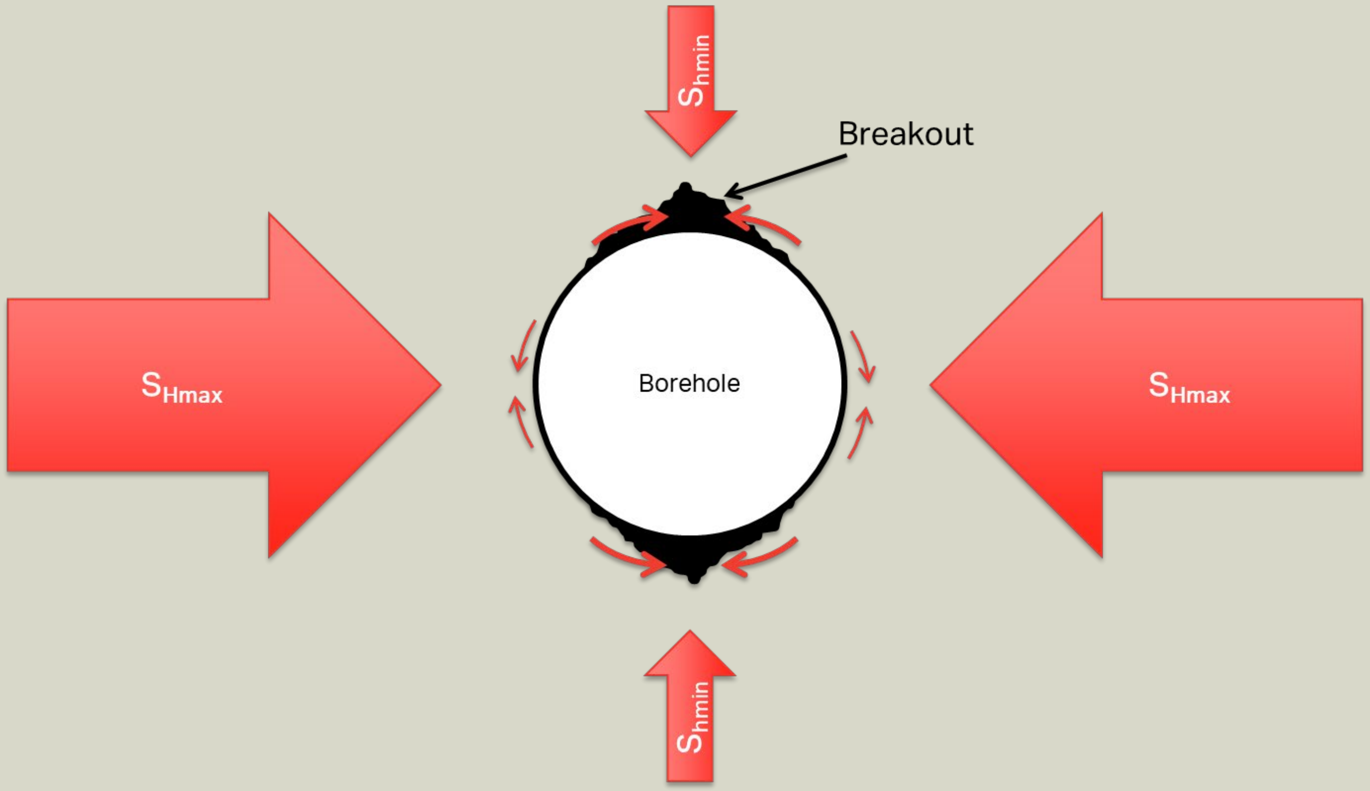
Technology Background

- Borehole breakouts are a proven indicator of the maximum horizontal in situ stress magnitude
- The thermal breakout technology is intended to reliably create breakouts by inducing thermal compressive stress

- Advantages: Access to obtaining SHmax, physical measurement
- Challenges: High power demand, rock mechanics correlation



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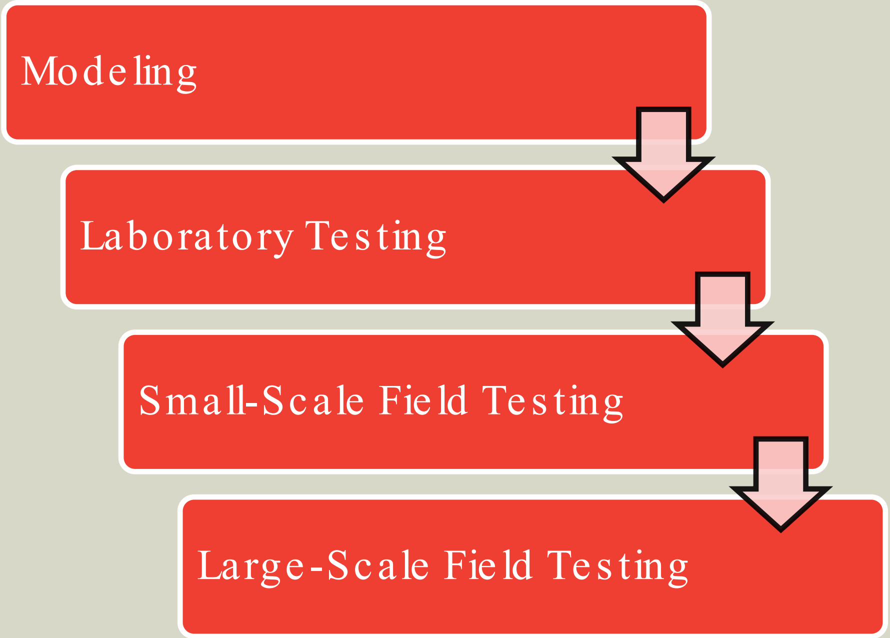
Technical Approach

- Logical work plan progression from theoretical concept to field demonstration
  - Modeling
    - Investigate the thermal breakout concept
    - Assess sensitivity and accuracy
  - Laboratory testing
    - Bench scale
    - Controlled conditions
  - Small-scale field testing
    - Build "rough" prototype downhole tool
    - Create thermal breakouts in easily-accessed deep environment
  - Large-scale field testing
    - Build near-production prototype tool
    - Demonstrate tool functionality and in situ thermal breakout development



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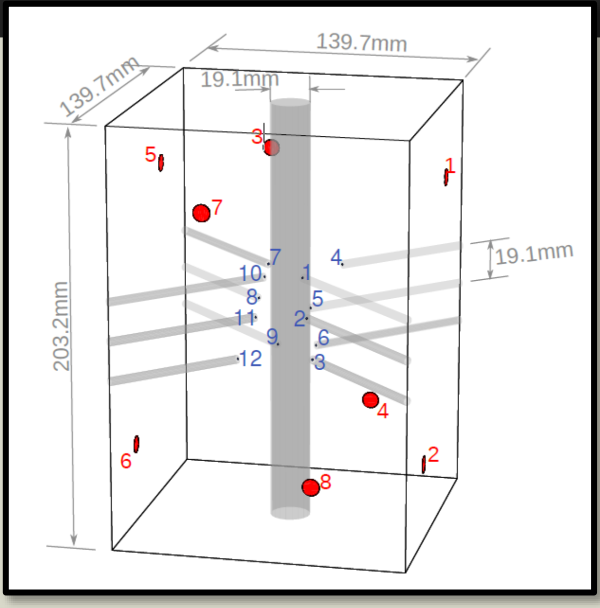
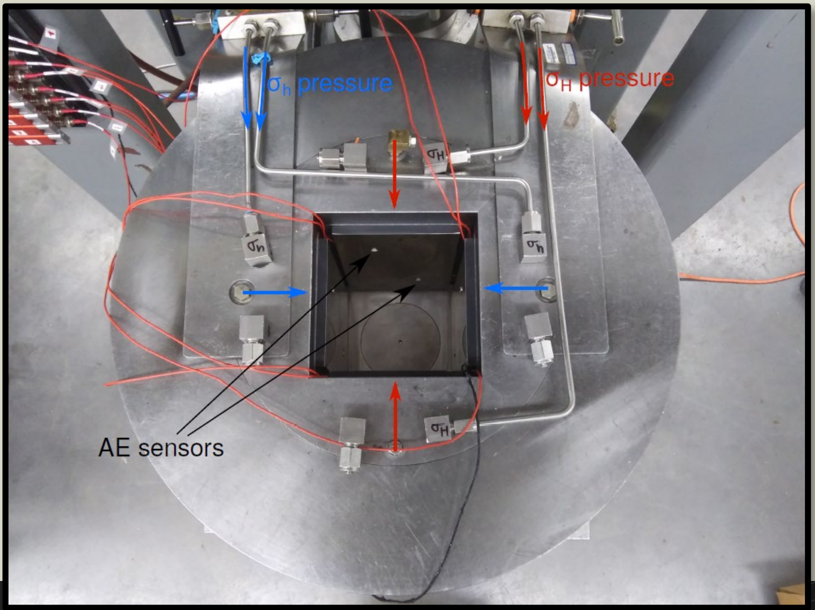
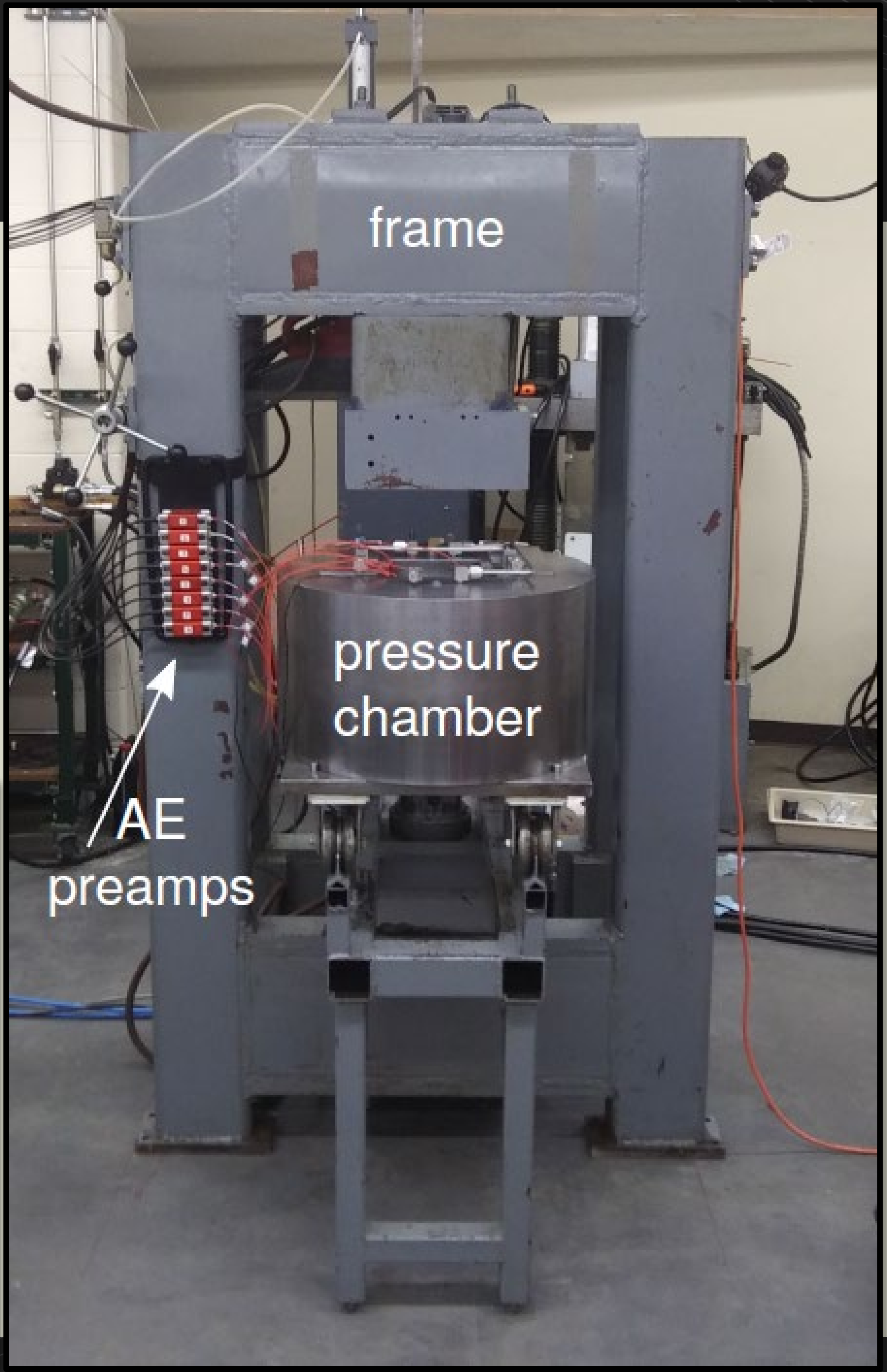
Lab Testing

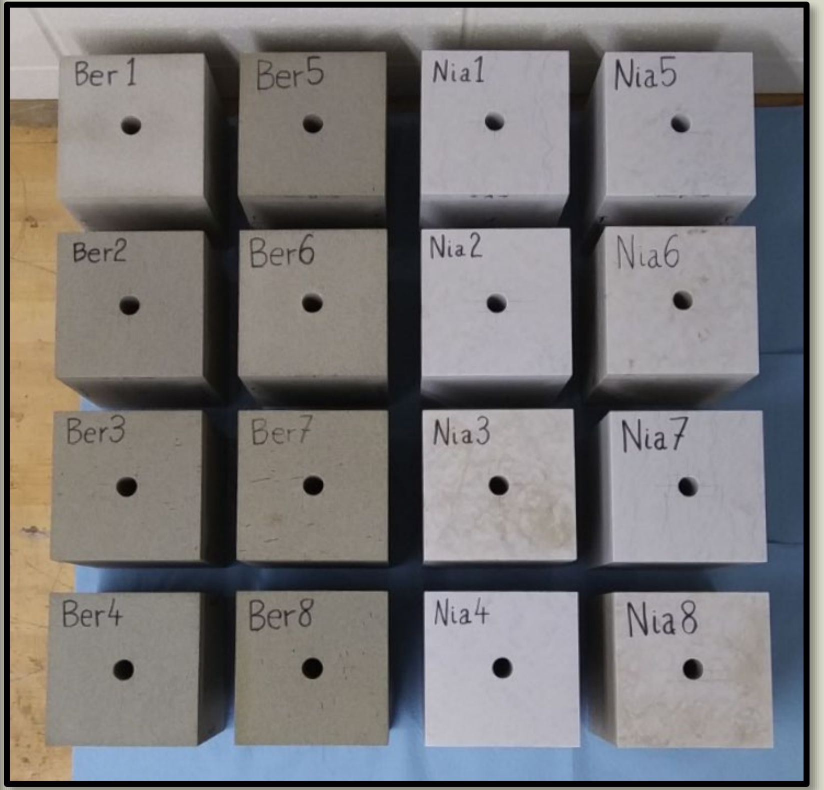
LAb Testing







Polyaxial Testing
Miniature Borehole



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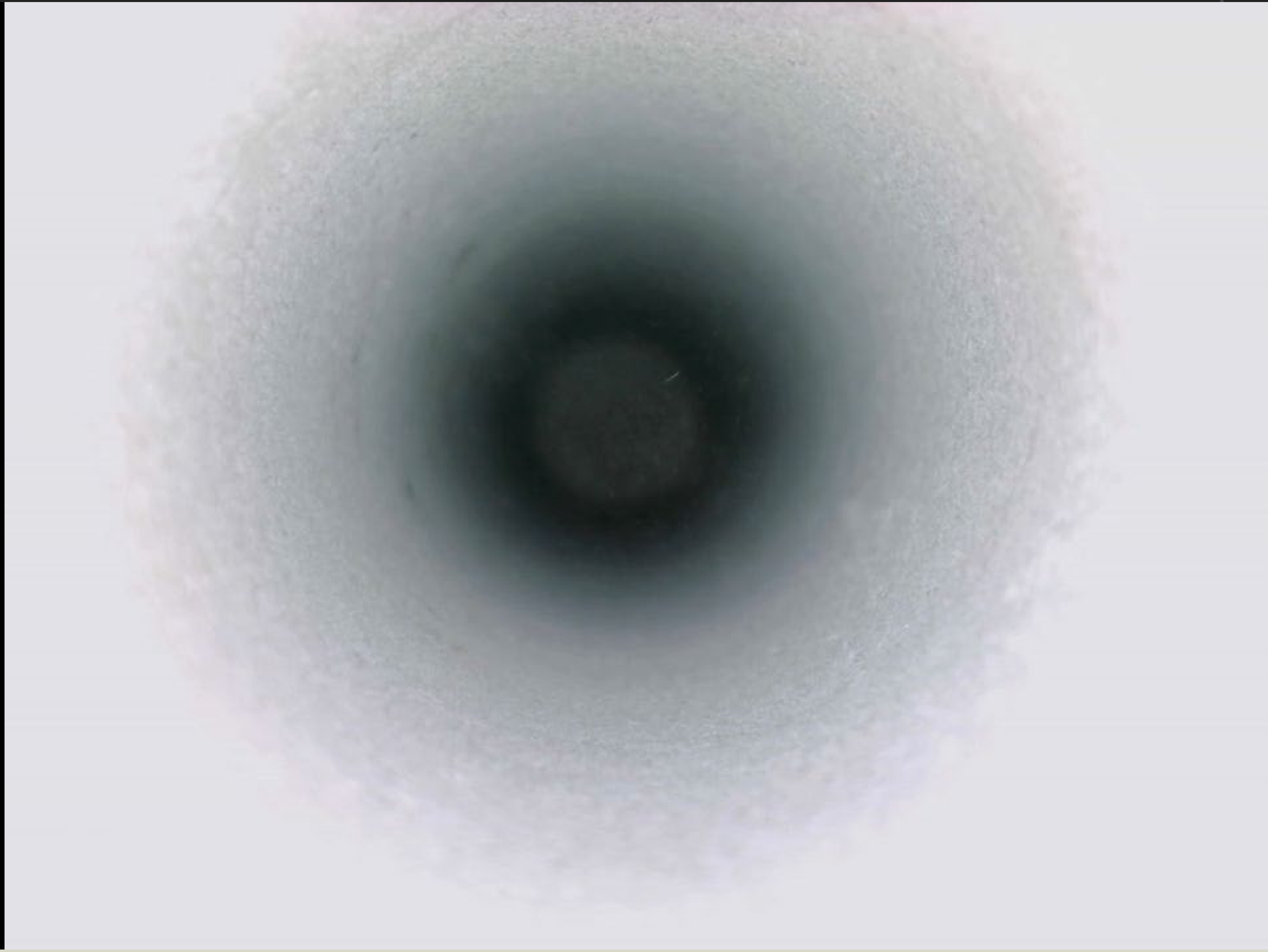
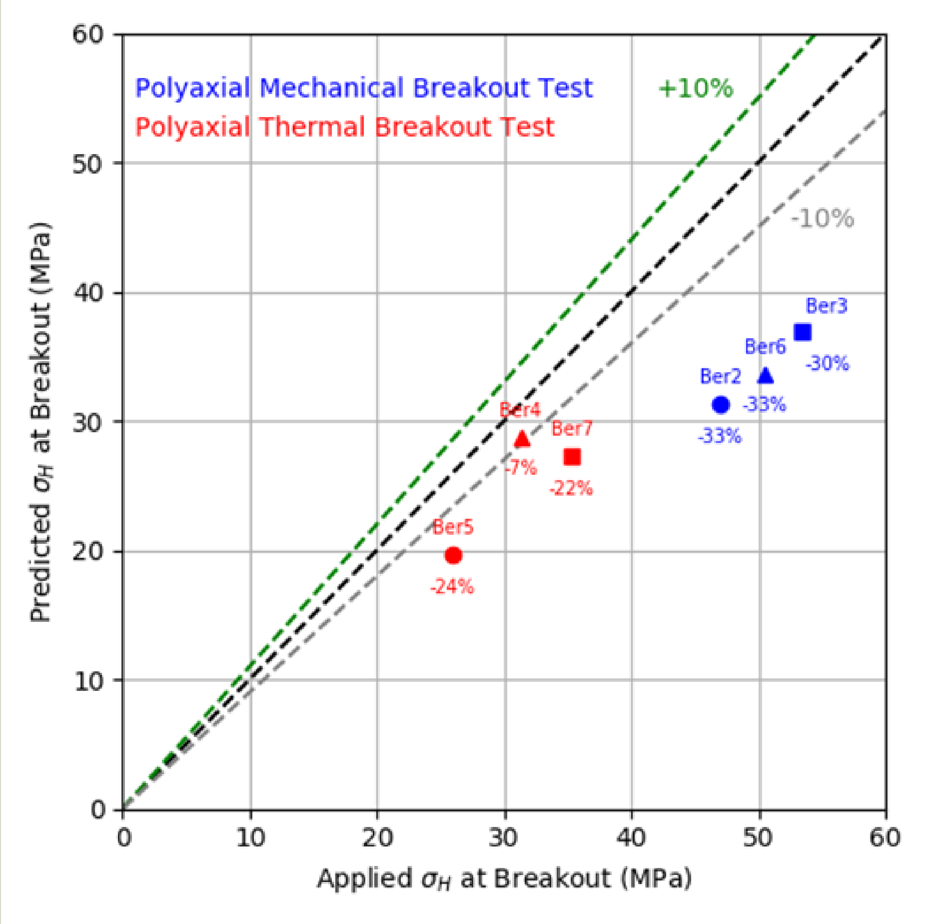


LAB TESTING

LAb Testing – SUmmary

- Successfully created borehole breakouts both mechanically and thermally
- Acoustic emission monitoring can detect breakout onset (including location and mechanism)
- Identified the importance of size effects in the laboratory and the use of polyaxial strength criteria
- Thermally-induced borehole breakouts show a correlation between temperature and in situ stress
- ...but more strength characterization is needed to quantify the stress state

Predicted σ_H vs. Applied σ_H



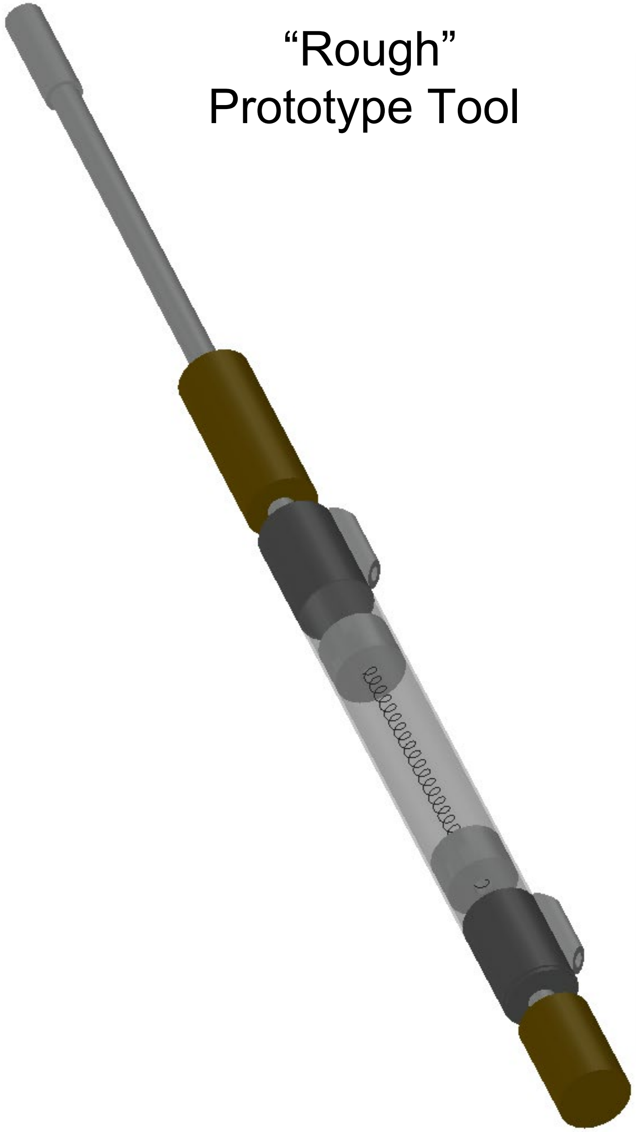
Small-Scale Field Testing

Small-Scale Field Testing

- Performed at the Sanford Underground Research Facility (SURF), Lead, South Dakota
- Abandoned gold mine converted to a science laboratory
- SURF provides easy and cost effective access to deep (>1500m) rock formations for in situ testing
- The RESPEC office is only 50 minutes from SURF
- The in situ stress state has already been measured and significant existing data already exists
- Many other DOE projects in progress at SURF

Small-Scale Field Testing

“Rough”
Prototype Tool



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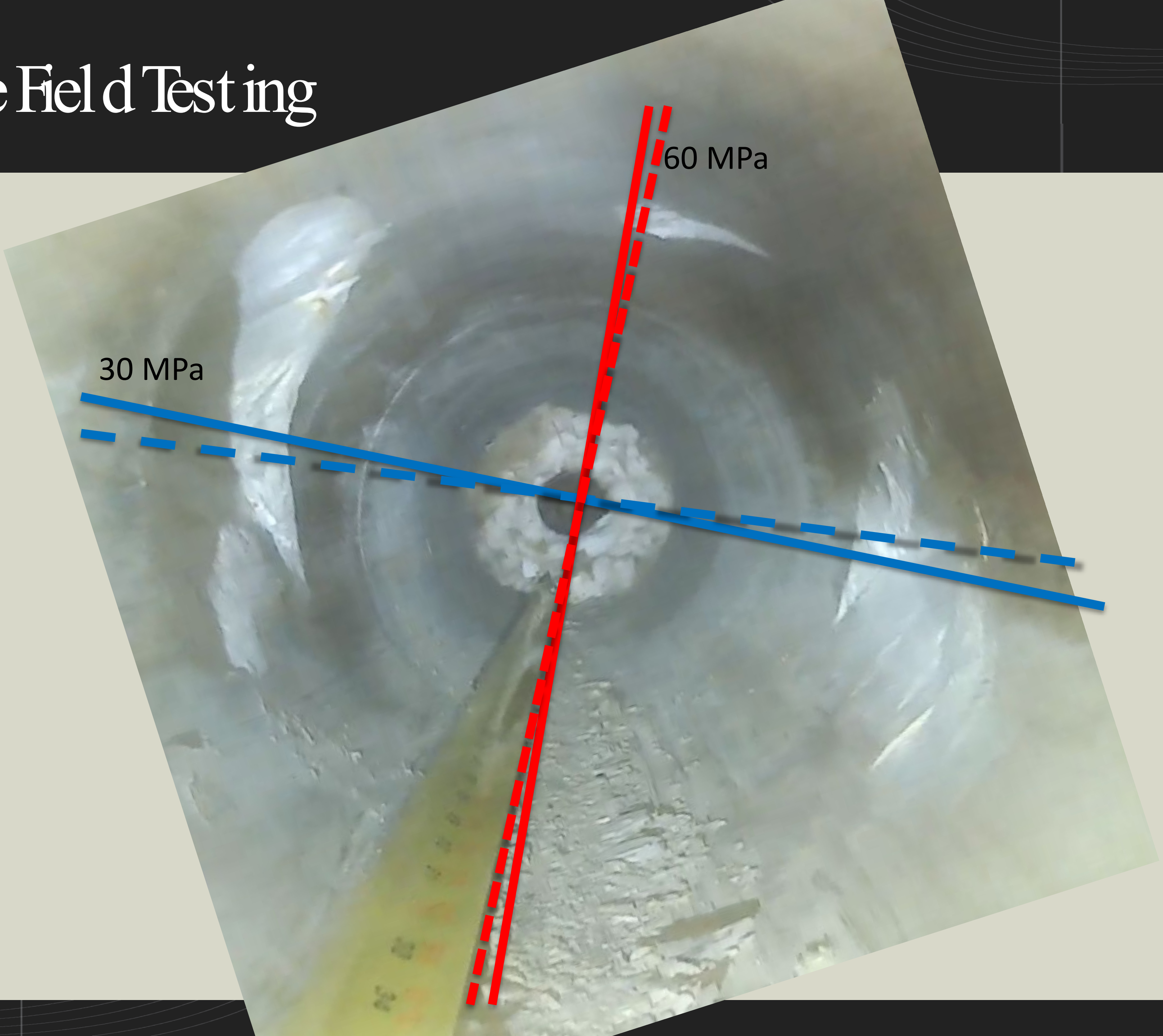

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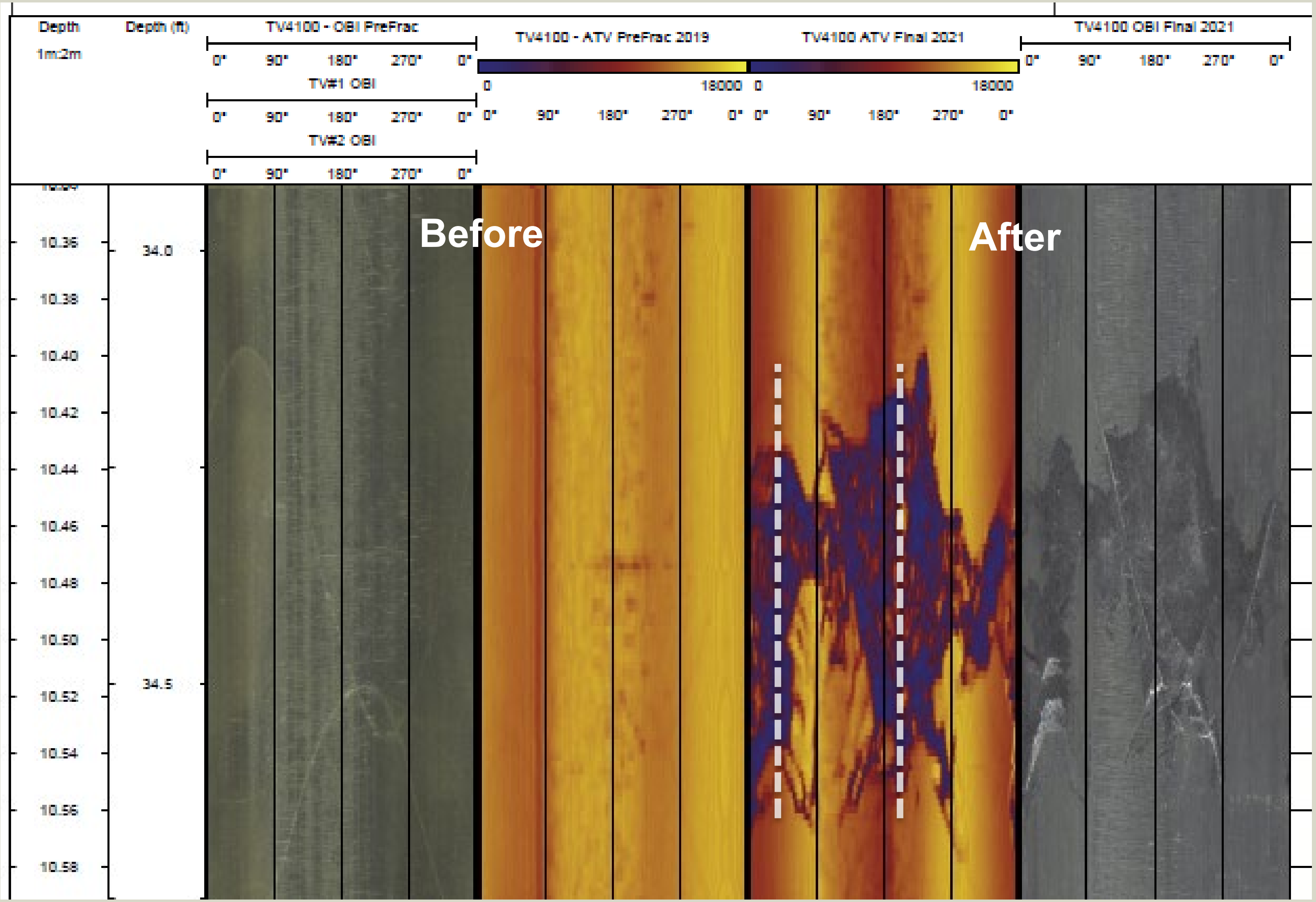

Large-Scale Field Testing

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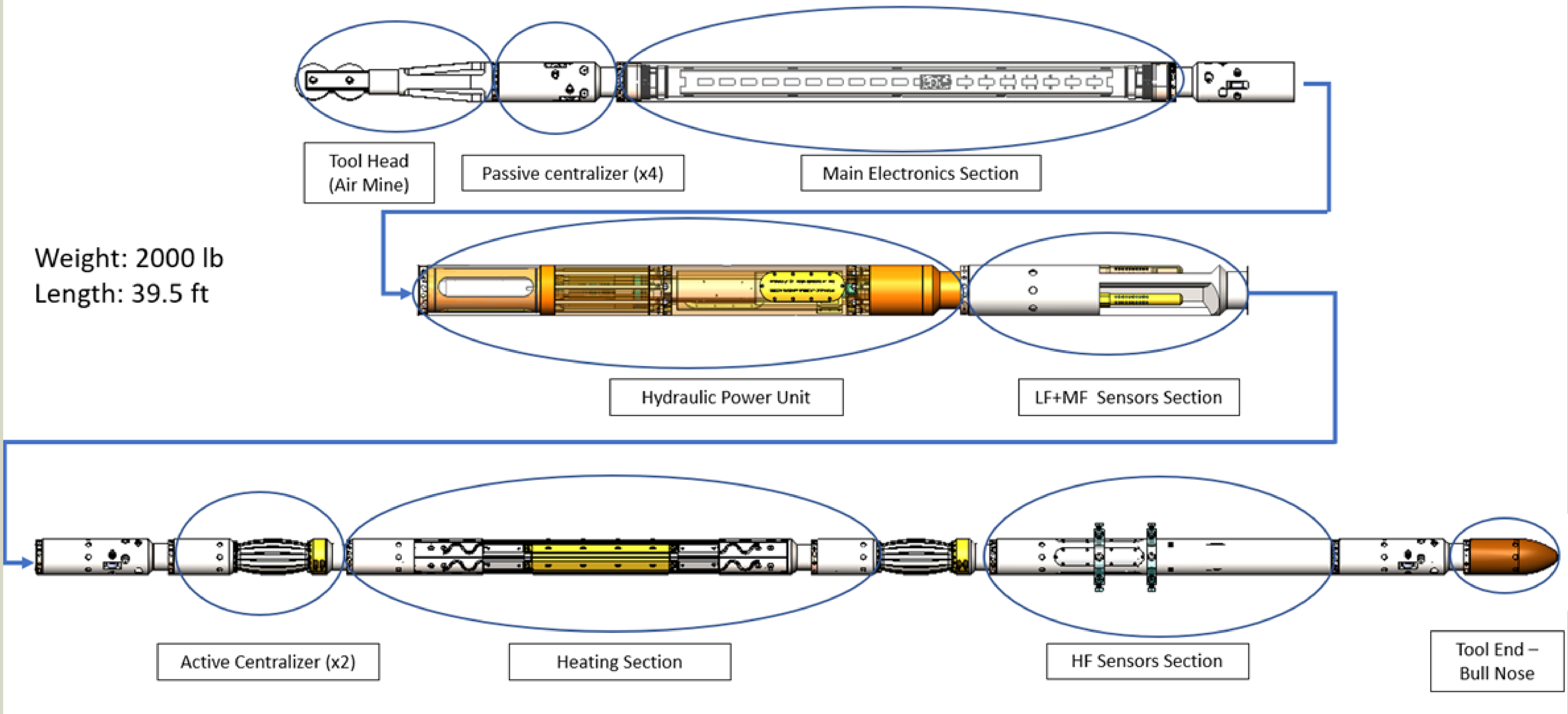
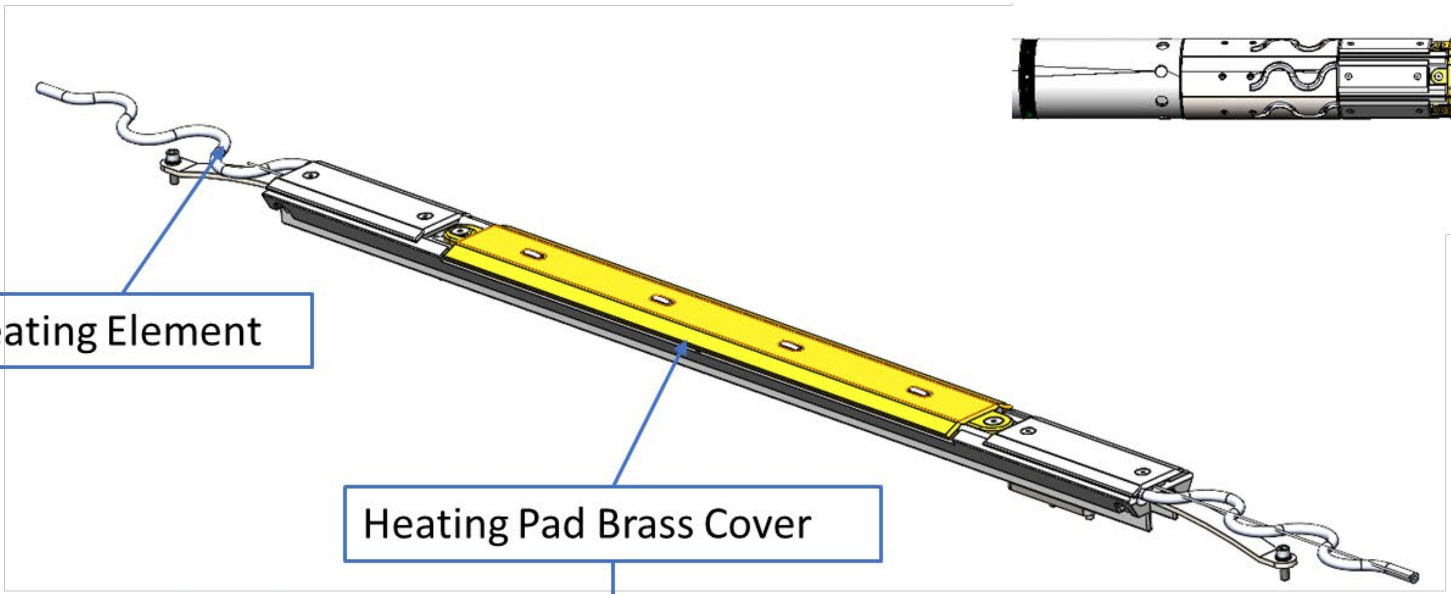
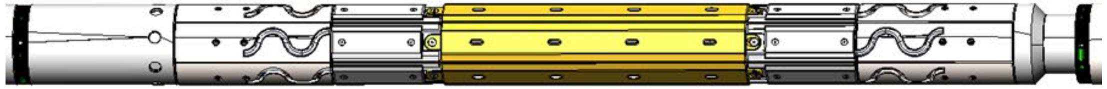
Large-Scale Field Testing

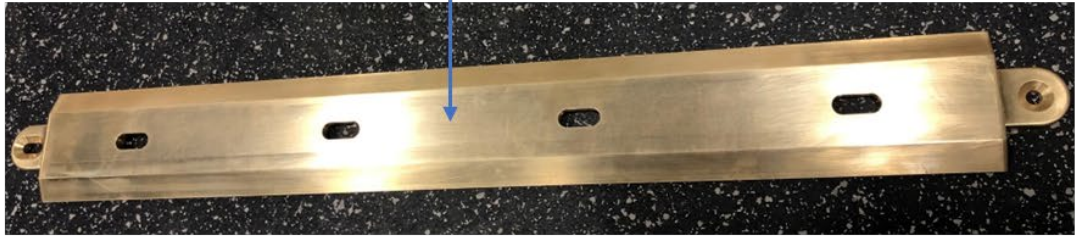


Weight: 2000 lb
Length: 39.5 ft

Large-Scale Field Testing







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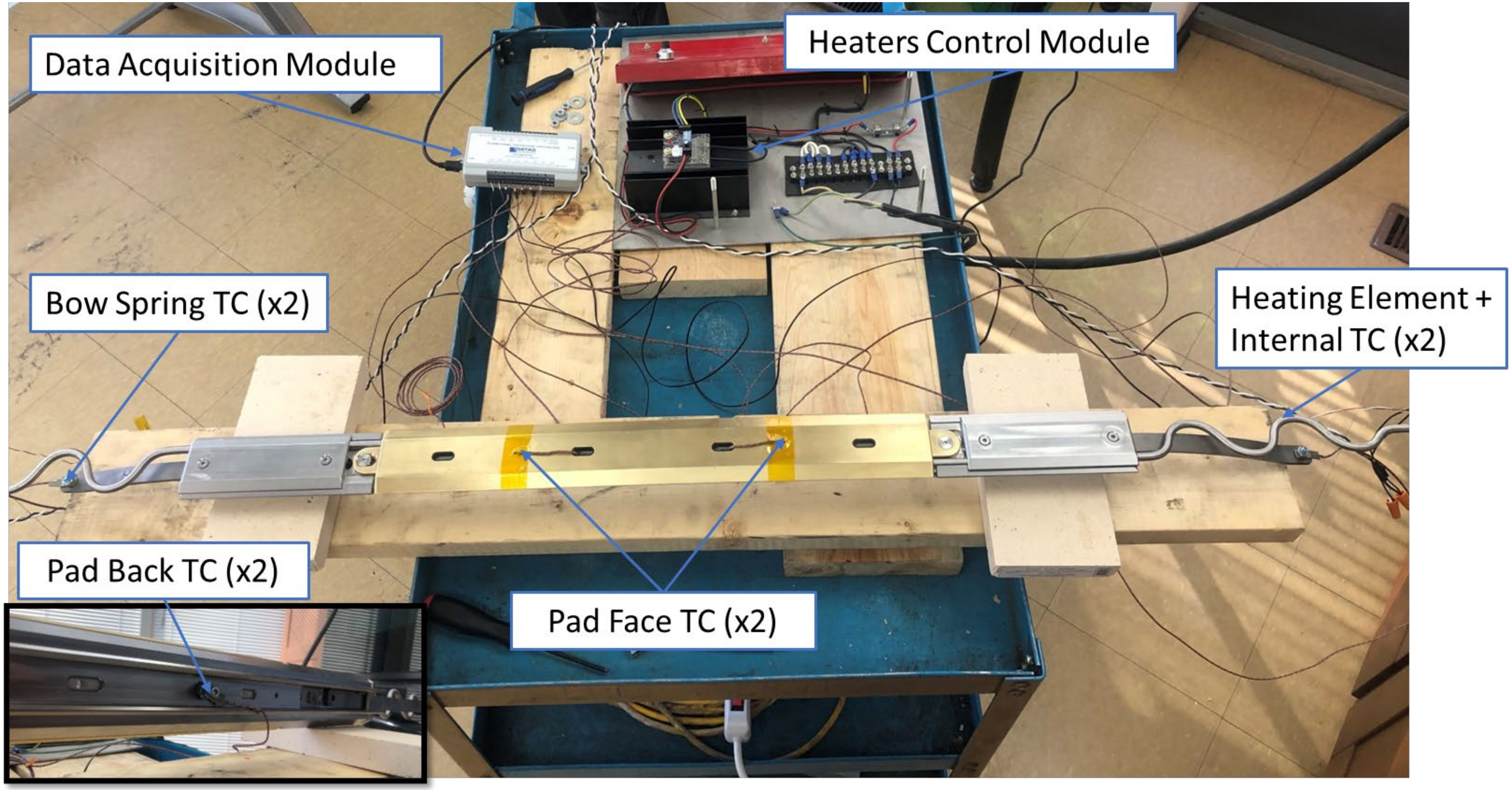

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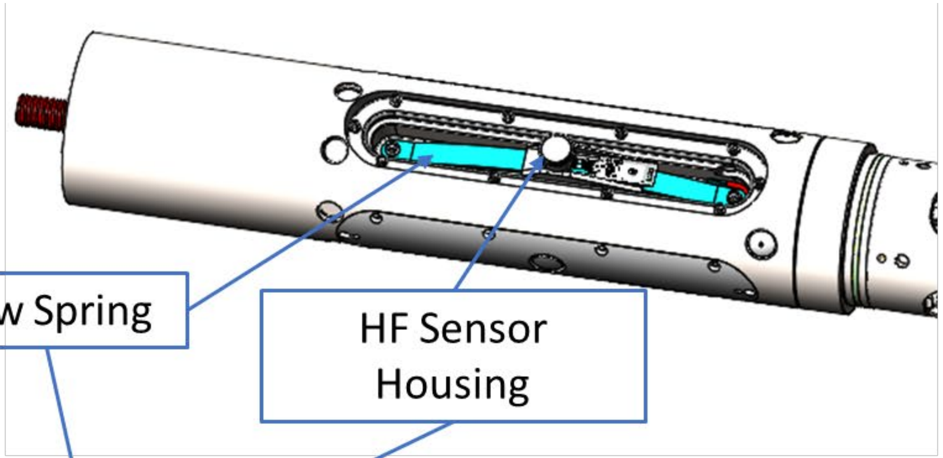

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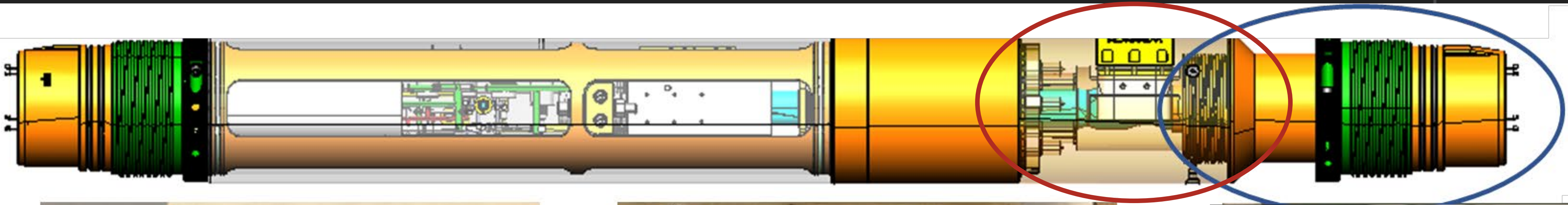

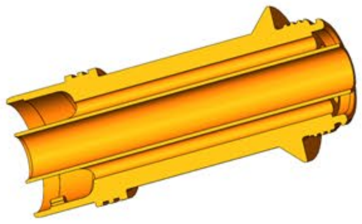

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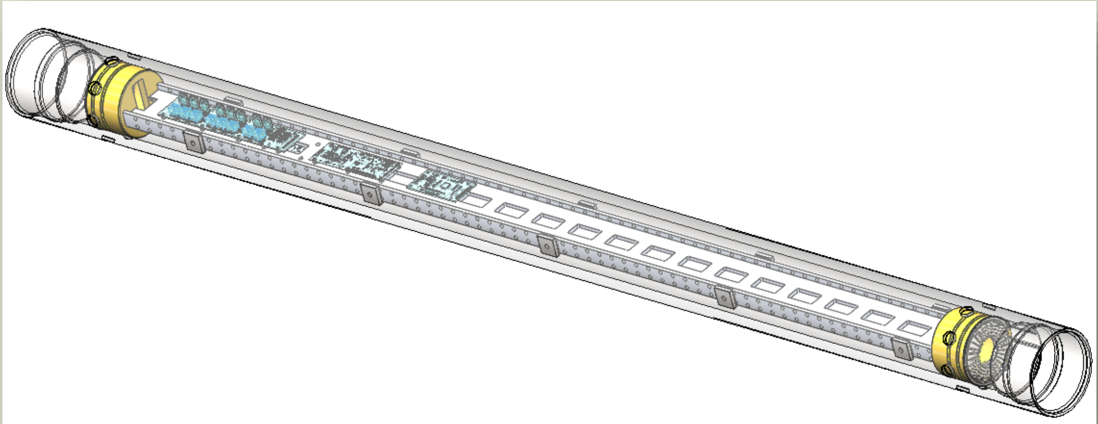

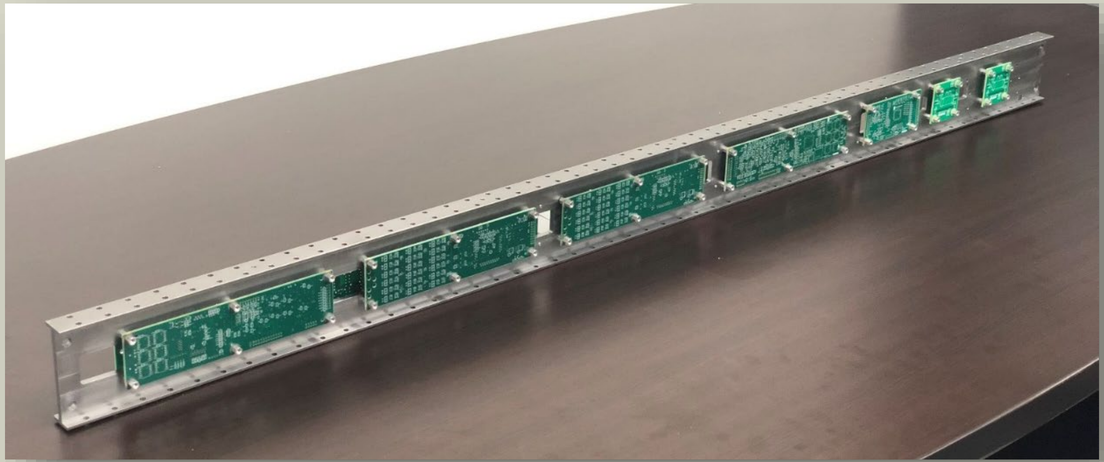

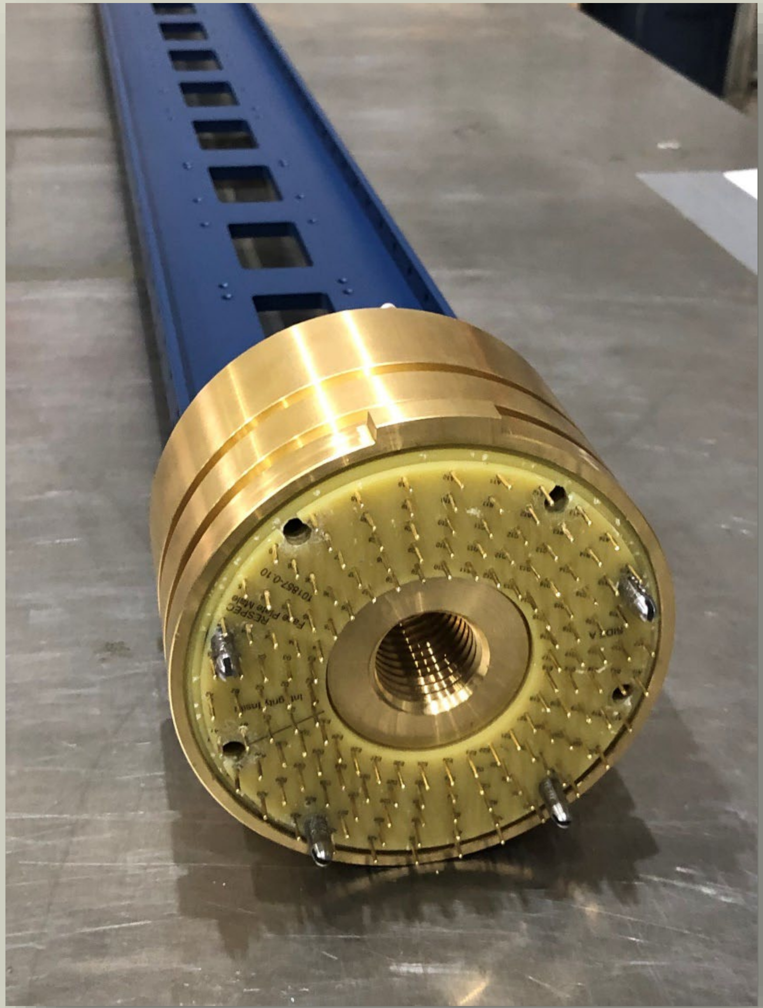

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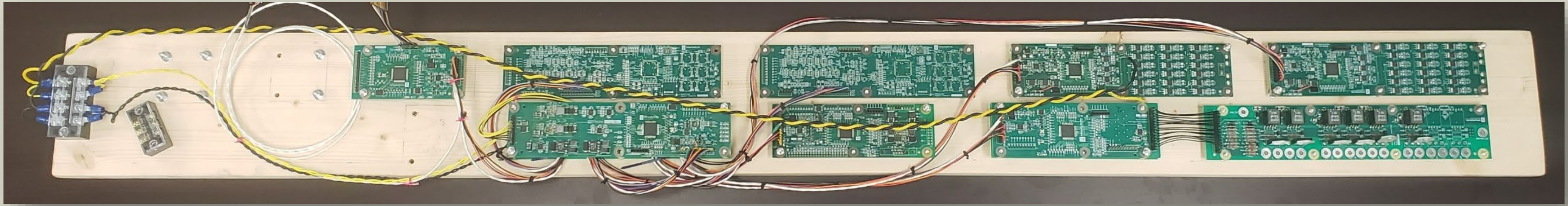

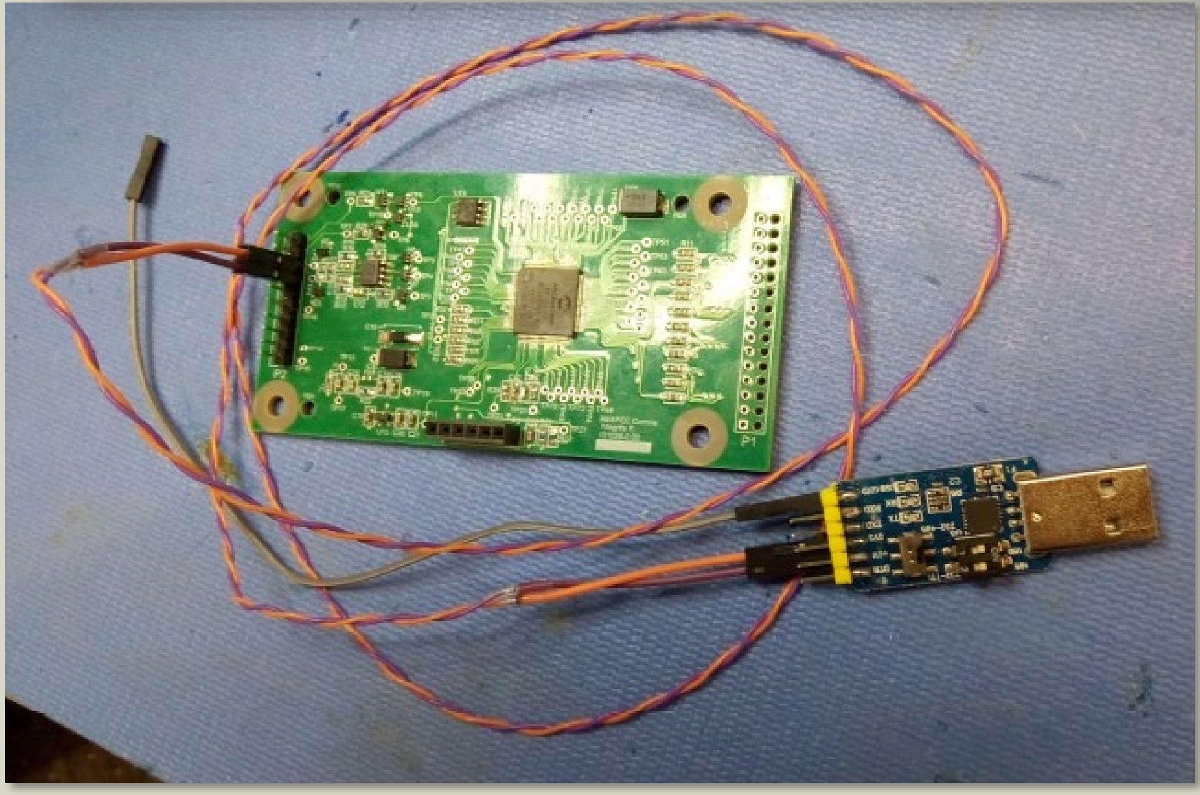

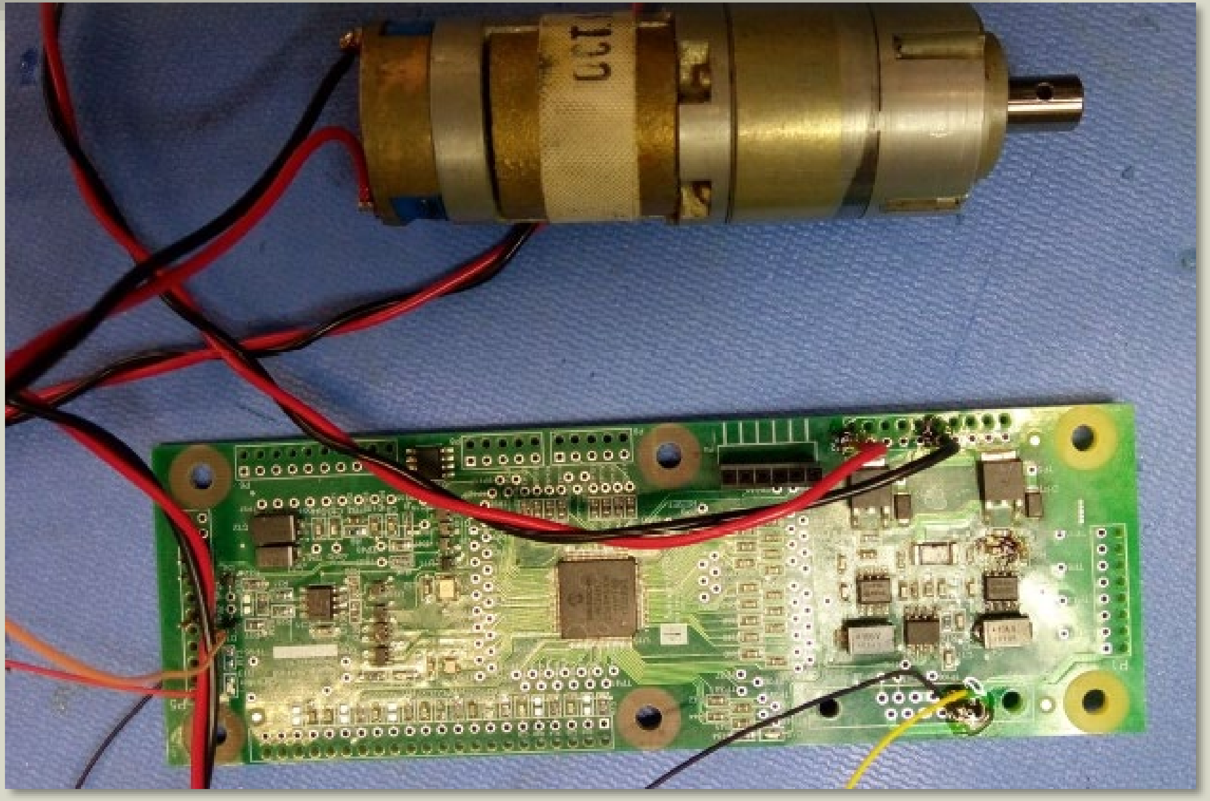

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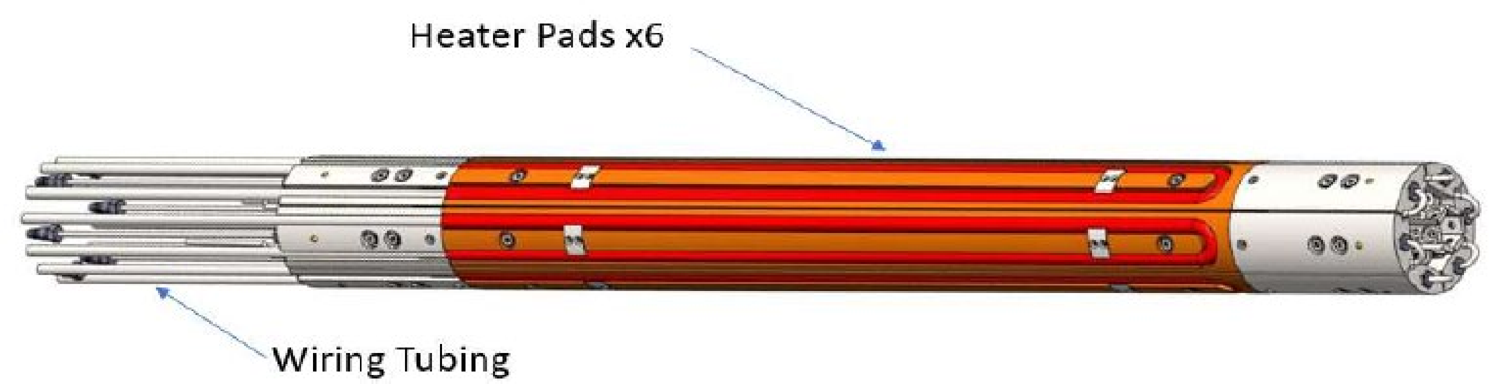
Future Plans

- Within Project:
  - Finish building near-commercial prototype tool (2024 Q1)
  - Complete prototype tool functionality testing in the small-scale field environment (2024 Q2)

- After Project:
  - Work with interested parties to further demonstrate, validate, and refine prototype tool
  - Partner with geophysical service provider(s) to commercialize and deploy the thermal breakout tool in industry (CCS, O&G, civil, mining, etc).



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Summary

- Key Findings:
  - Heat can consistently induce breakouts (in lab and field)
  - Thermal breakout onset and orientation correspond to stress magnitude and direction
  - Rock strength and acoustic emission criteria are critical
- Lessons Learned:
  - Anticipate some partnering/contracting challenges
  - Benefits of preliminary but simple tests for initial proof of concept/learning
  - Supply and material costing issues in response to post-pandemic market!
- Take-away:
  - Thermal breakout technology is another tool in the toolbox to help design and operate safe geologic CO_2 sequestration

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