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
2022 Carbon Management Project Review Meeting
August 15 - 19, 2022

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

RANGE RESOURCES®

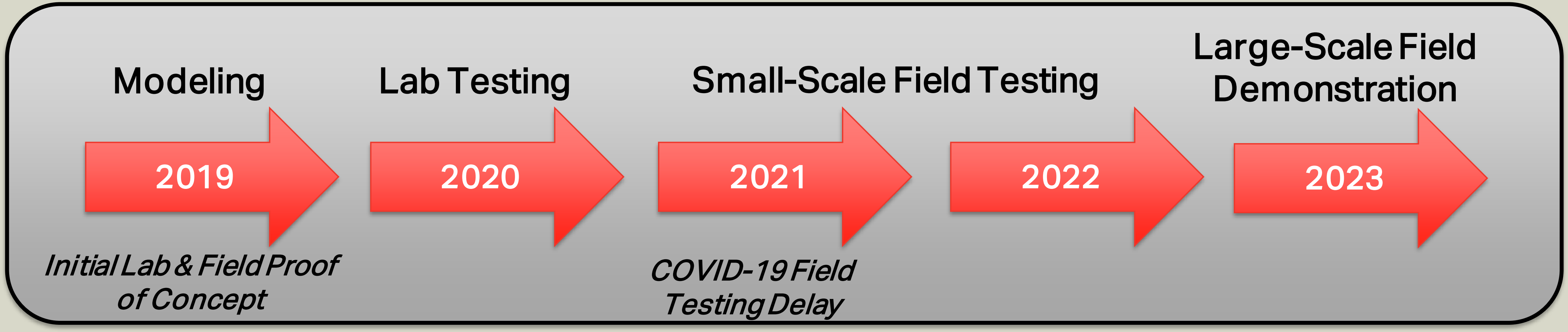
BERKELEY LAB

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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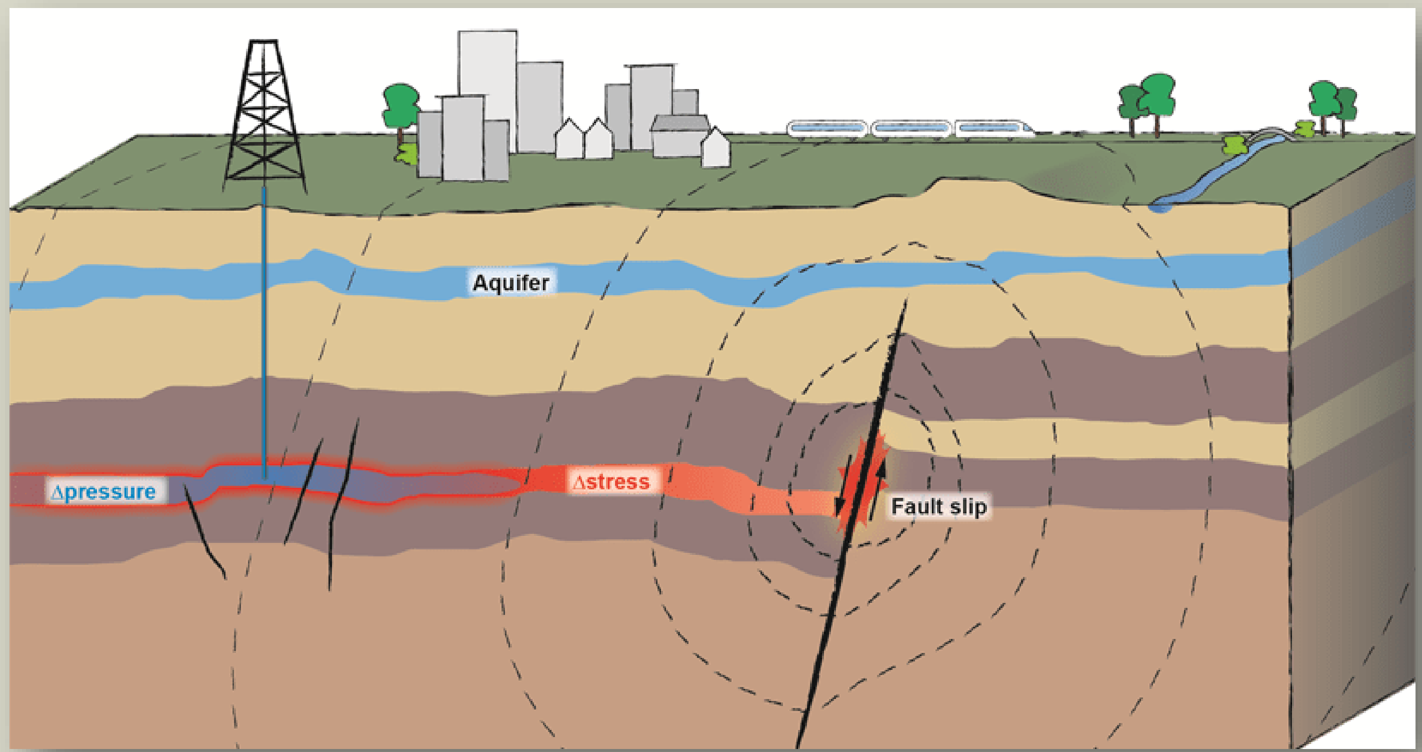
TECHNOLOGY BACKGROUND

- 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]

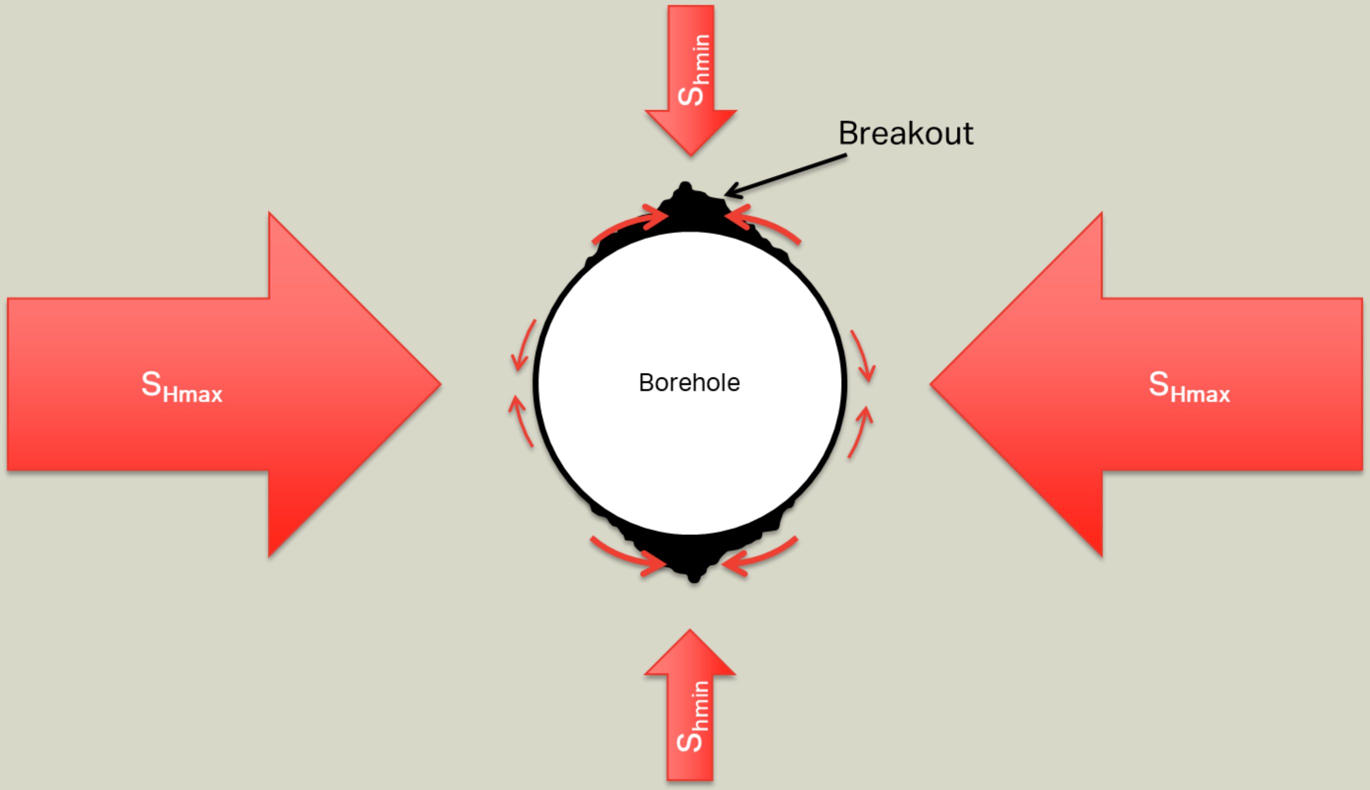
TECHNOLOGY BACKGROUND

- 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

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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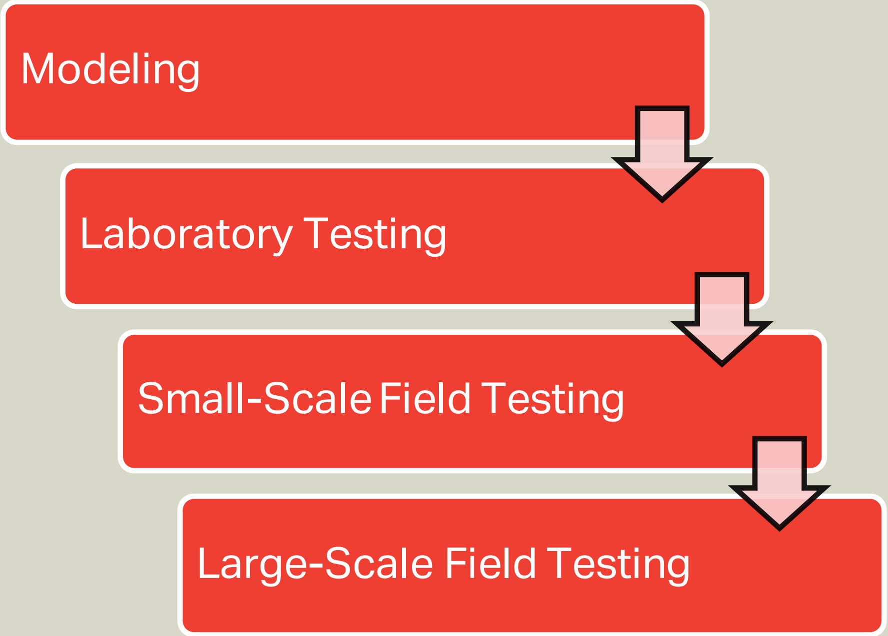
TECHNICAL APPROACH

- 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

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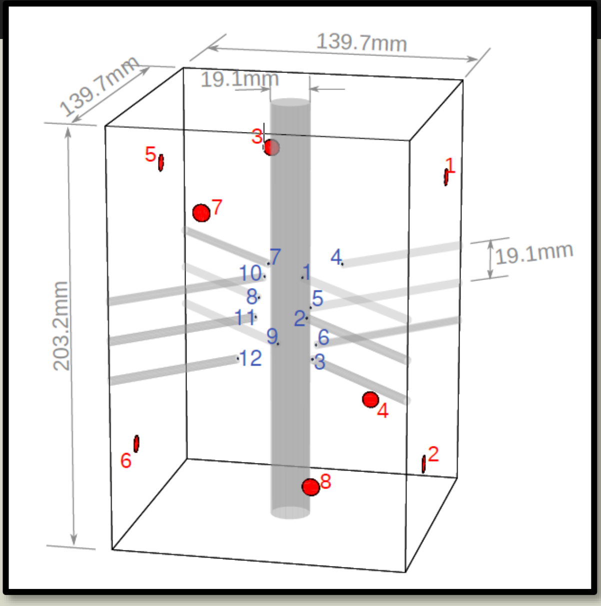
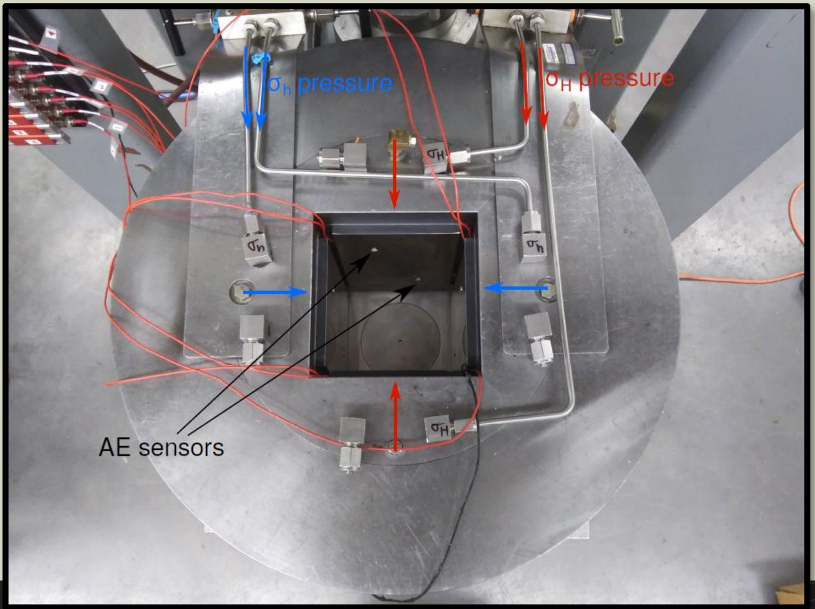
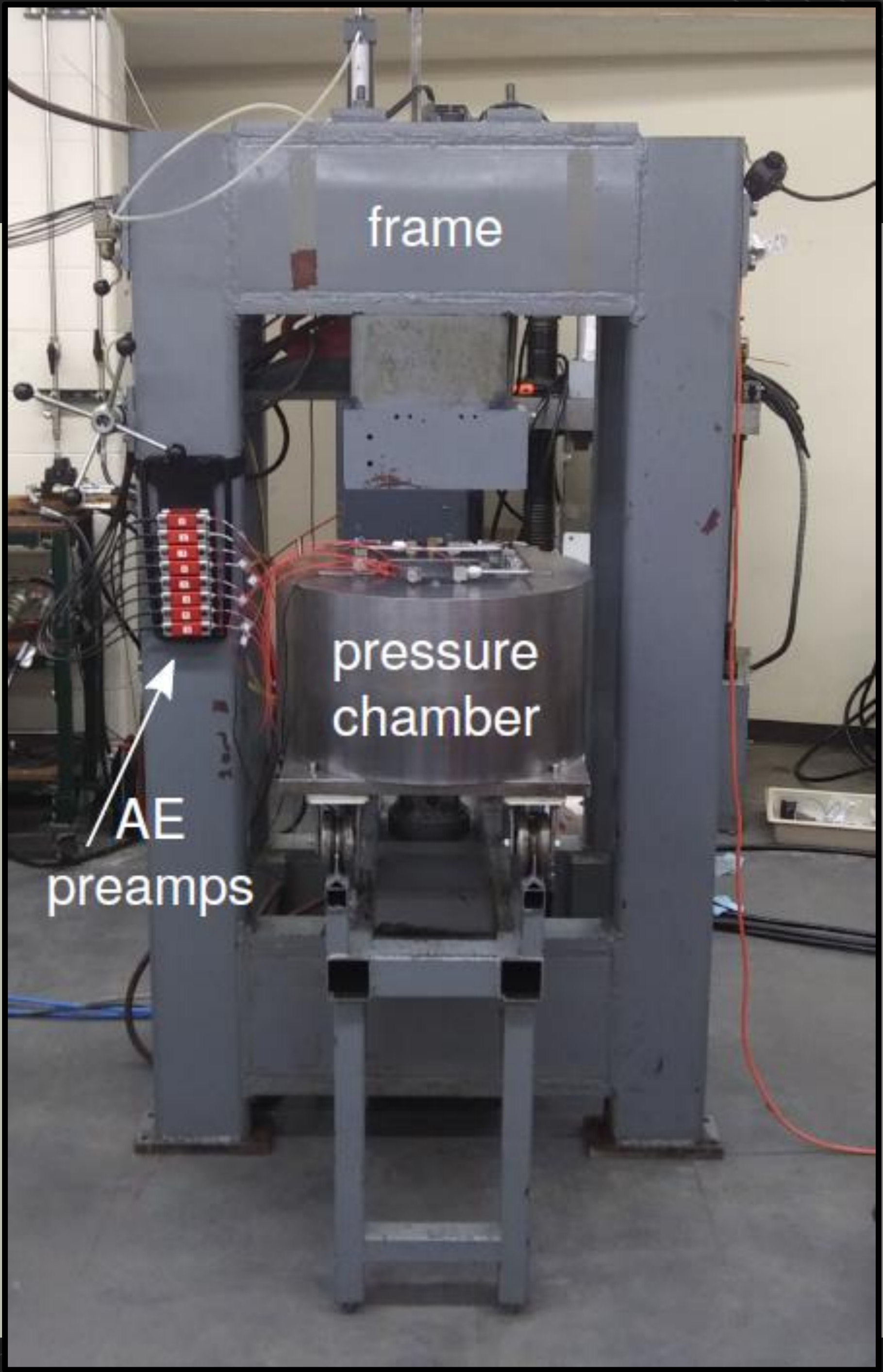
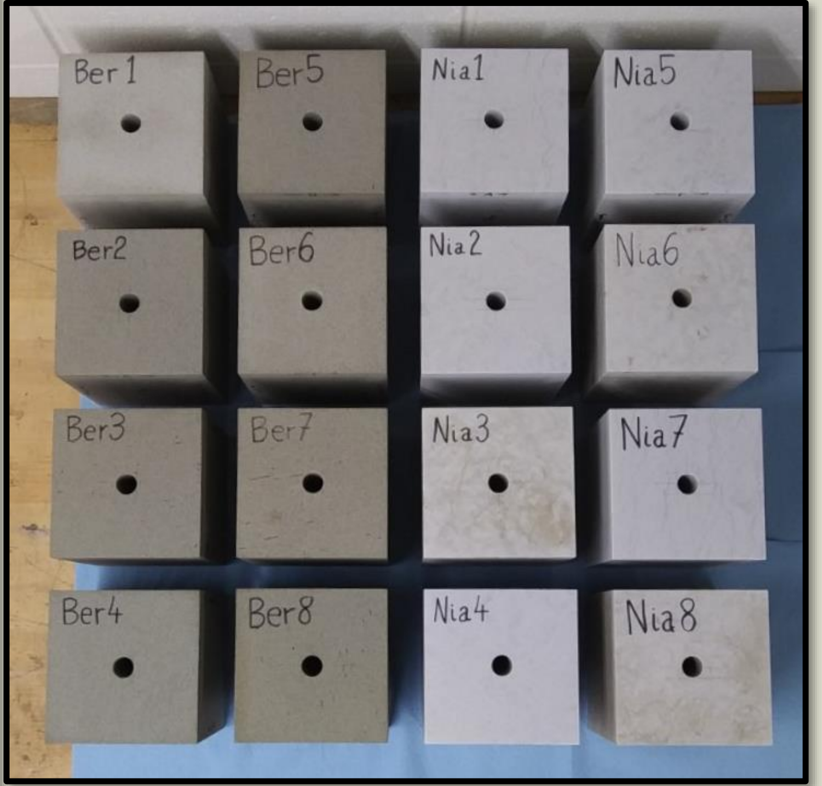






Polyaxial Testing Miniature Borehole



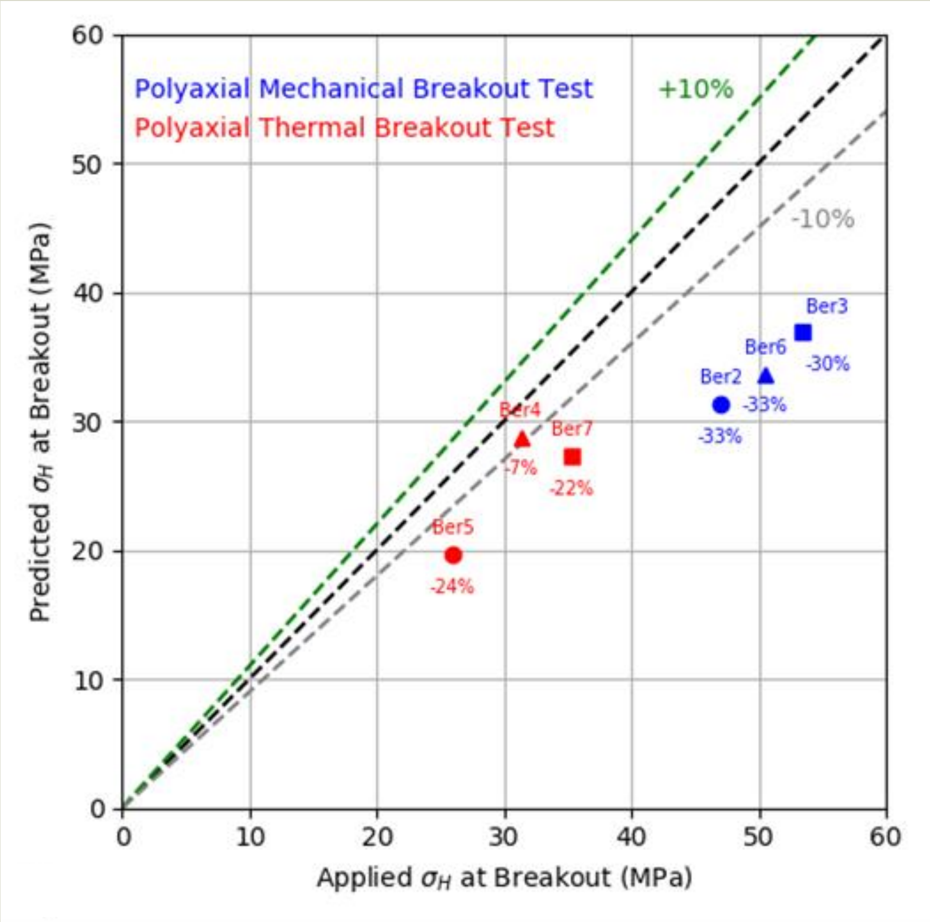
LAB TESTING

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

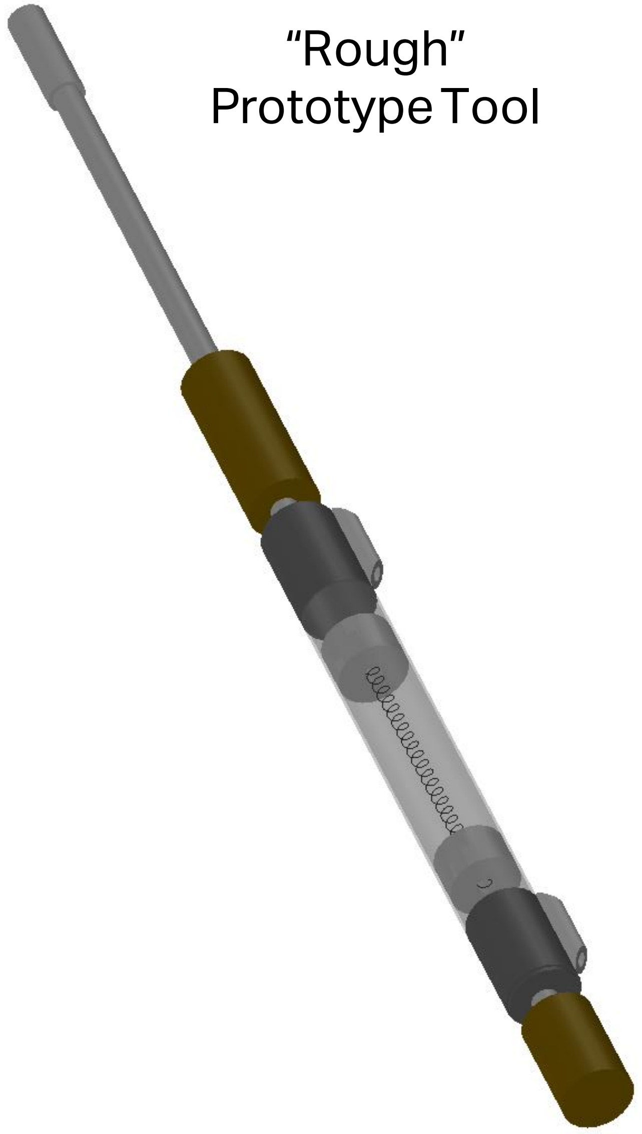


SMALL-SCALE FIELD TESTING

SMALL-SCALE FIELD TESTING

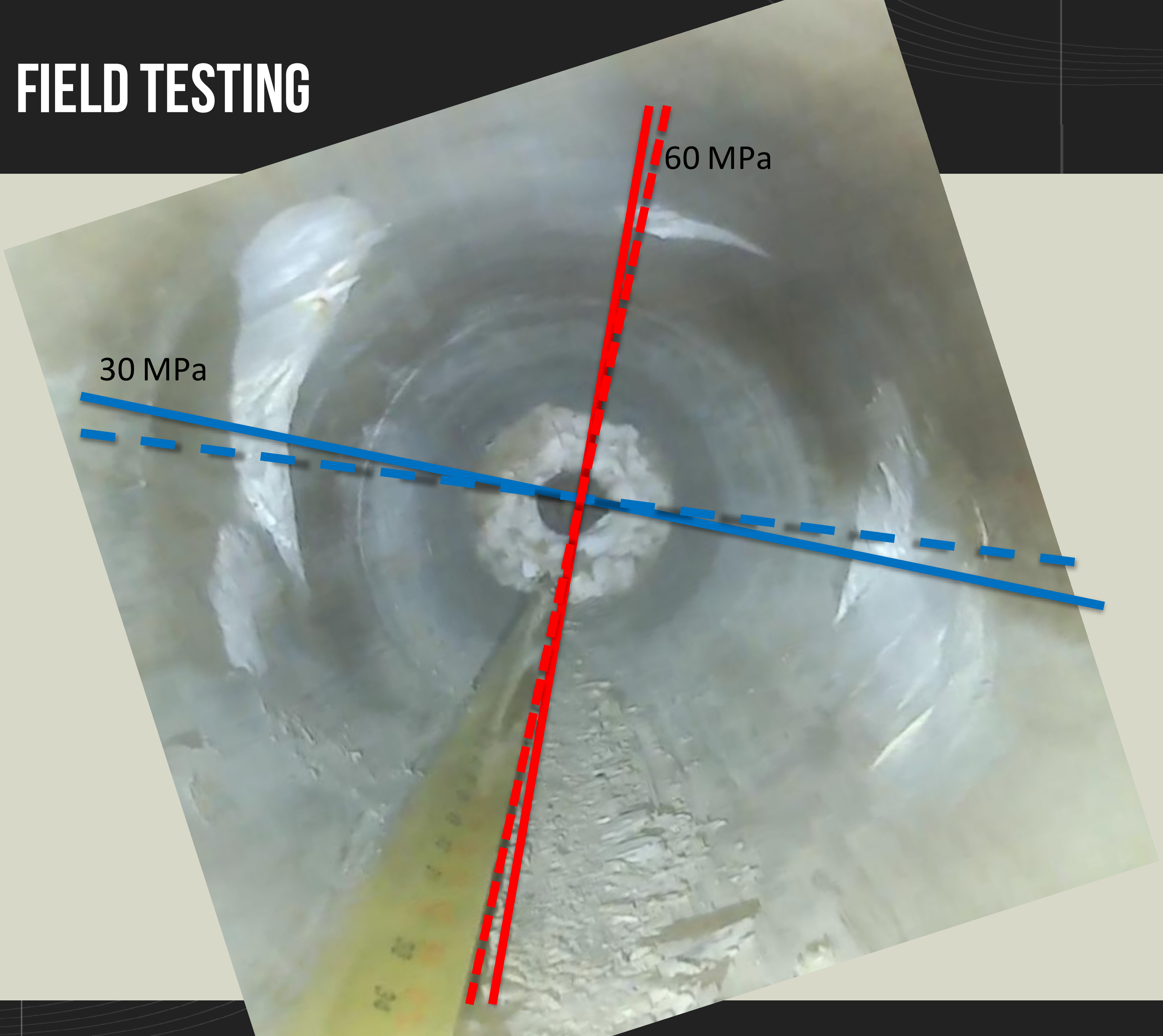
- Performed at the Sanford Underground Research Facility (SURF), Lead, South Dakota
- Abandoned gold mine converted to a science laboratory
- SURF provides easy and cost effective access to deep (>1500m) rock formations for in situ testing
- The RESPEC office is only 50 minutes from SURF
- The in situ 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

SMALL-SCALE FIELD TESTING



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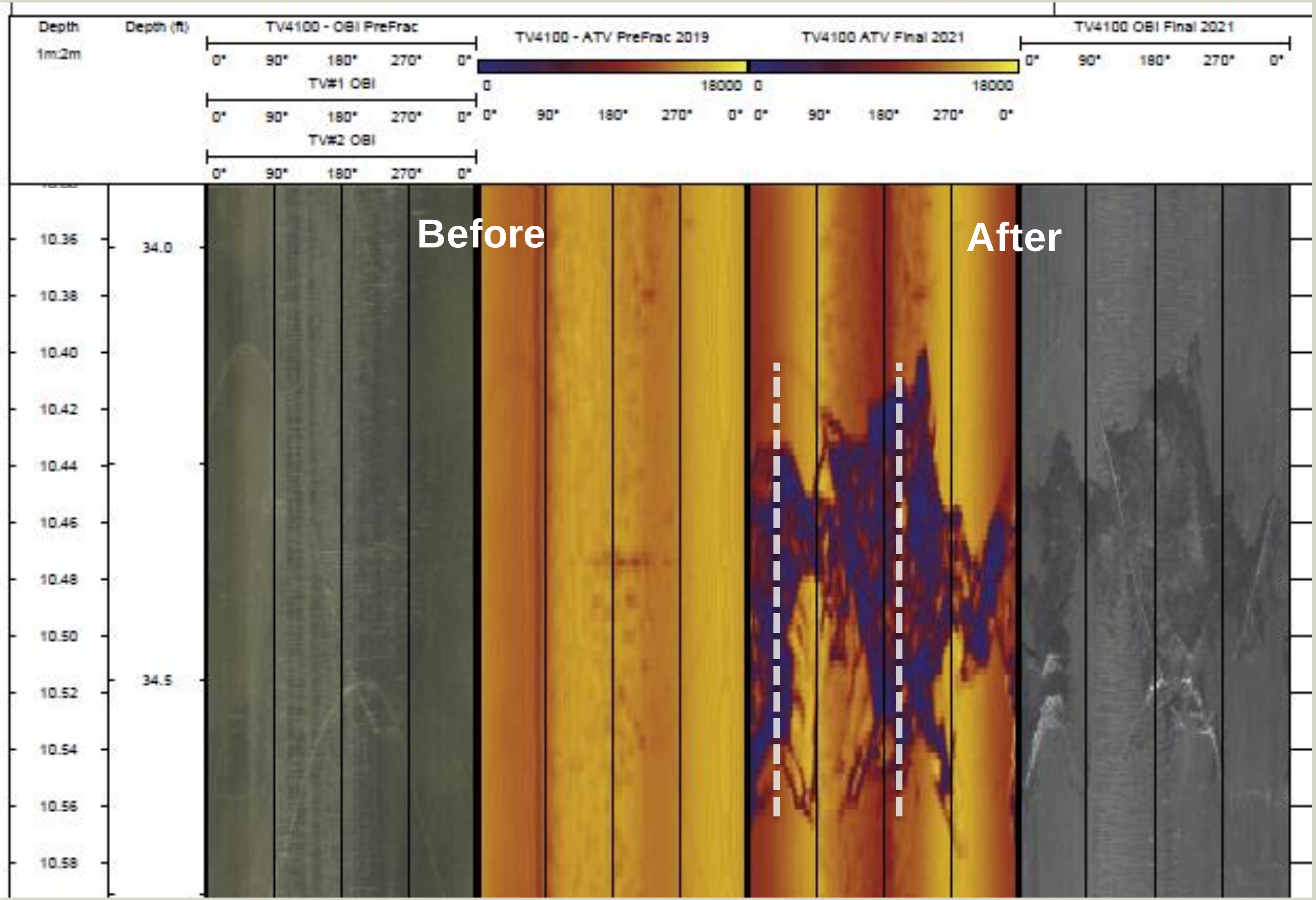

LARGE-SCALE FIELD TESTING

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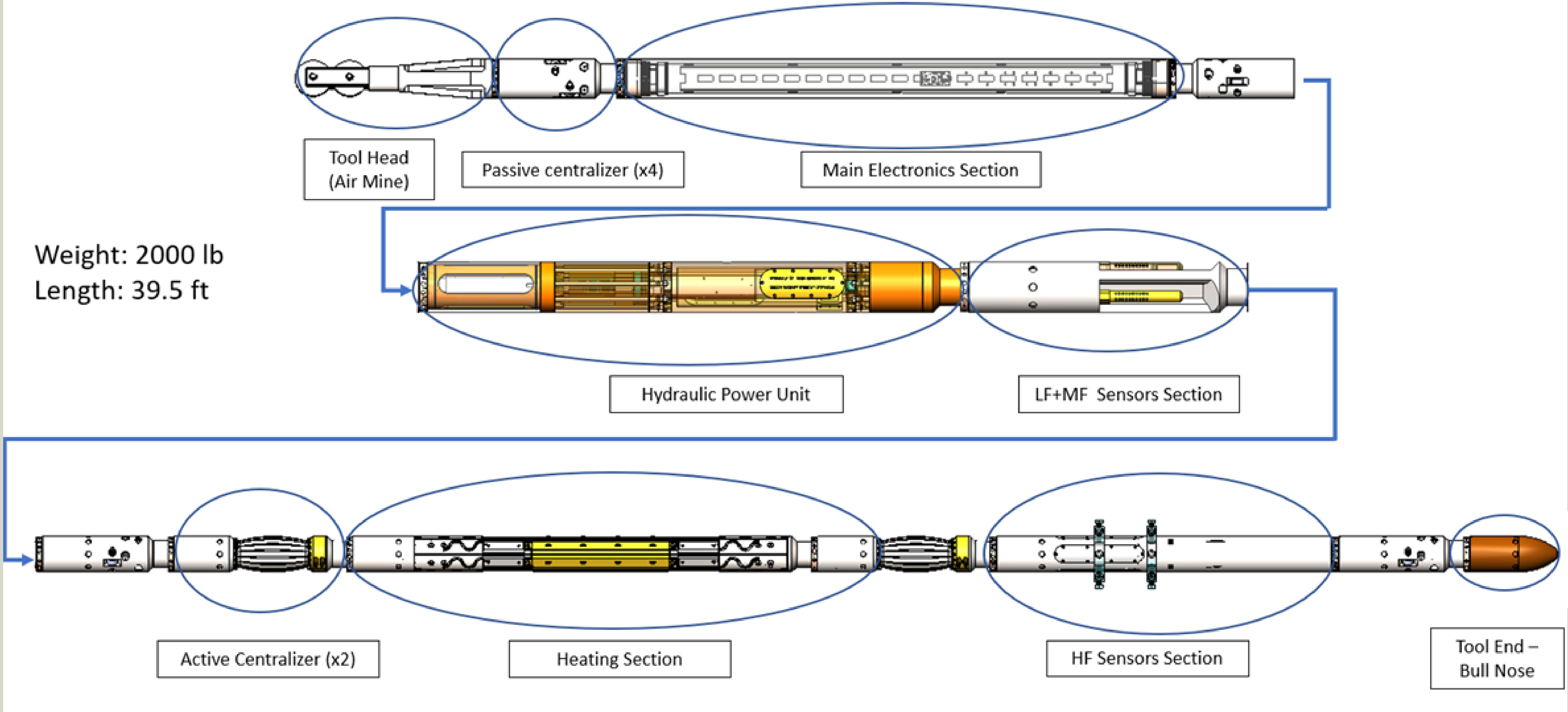
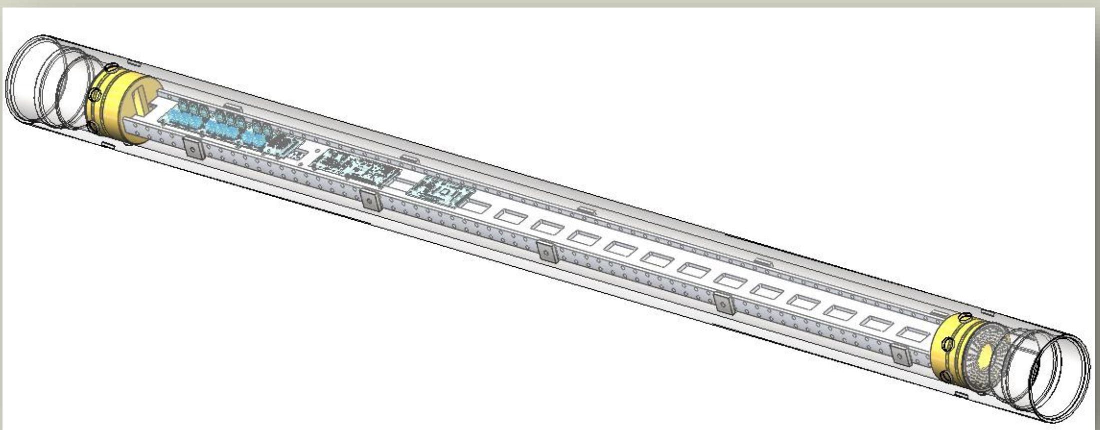
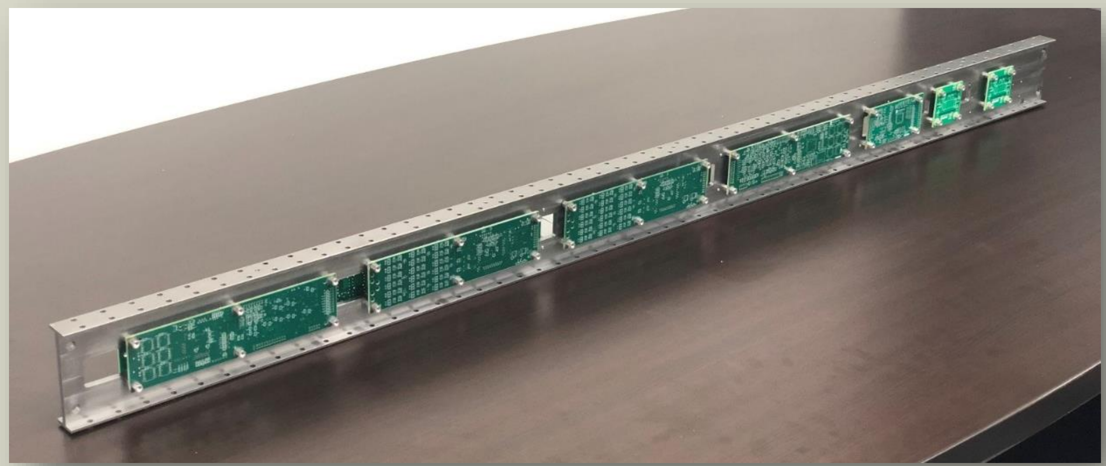
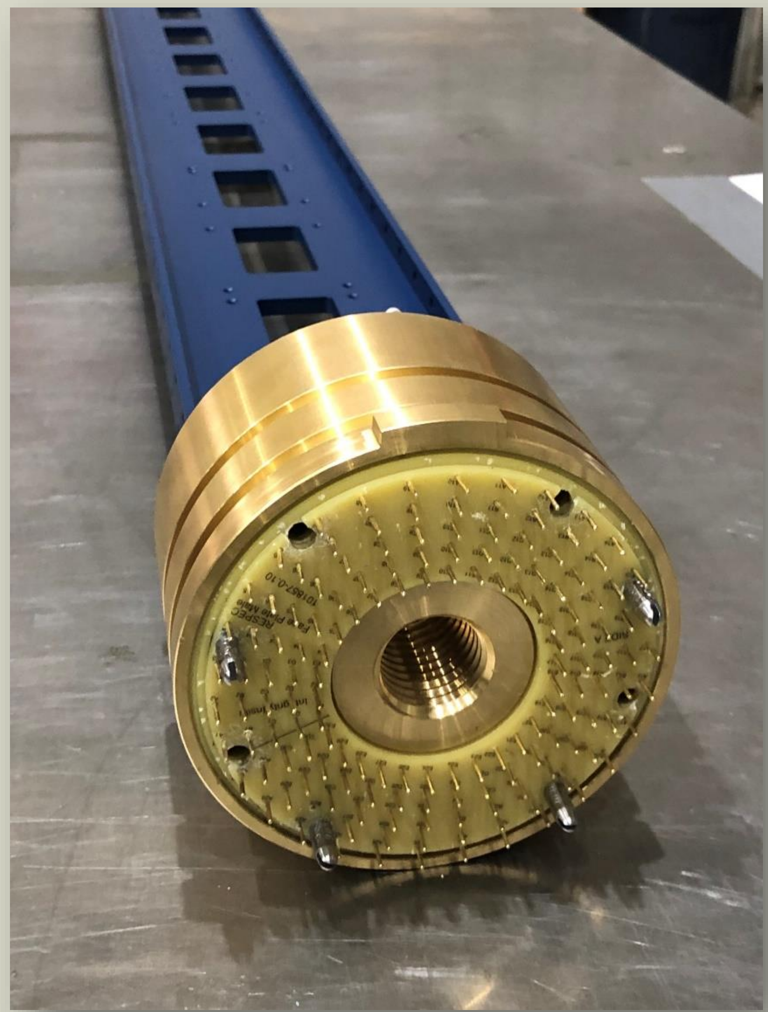


Weight: 2000 lb
Length: 39.5 ft

LARGE-SCALE FIELD TESTING







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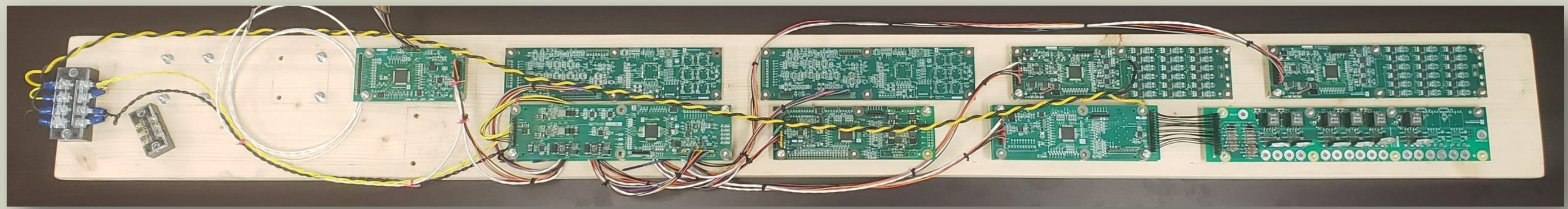

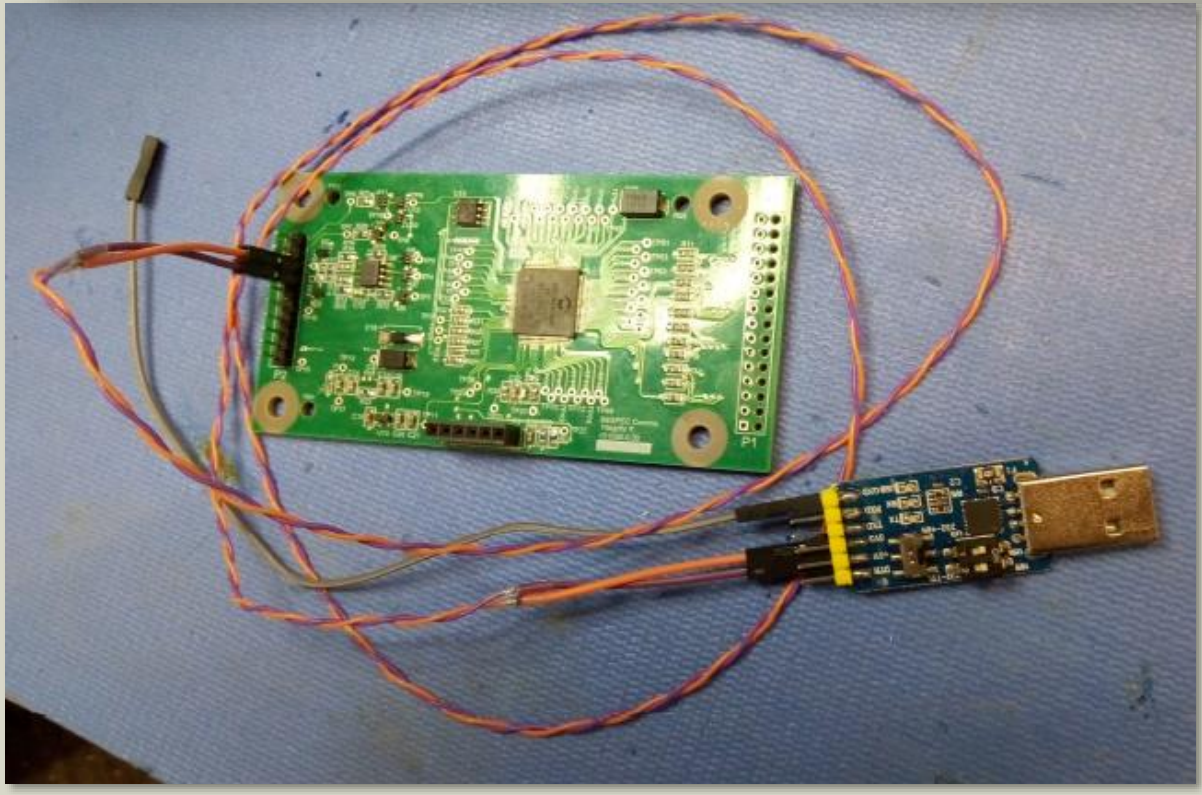

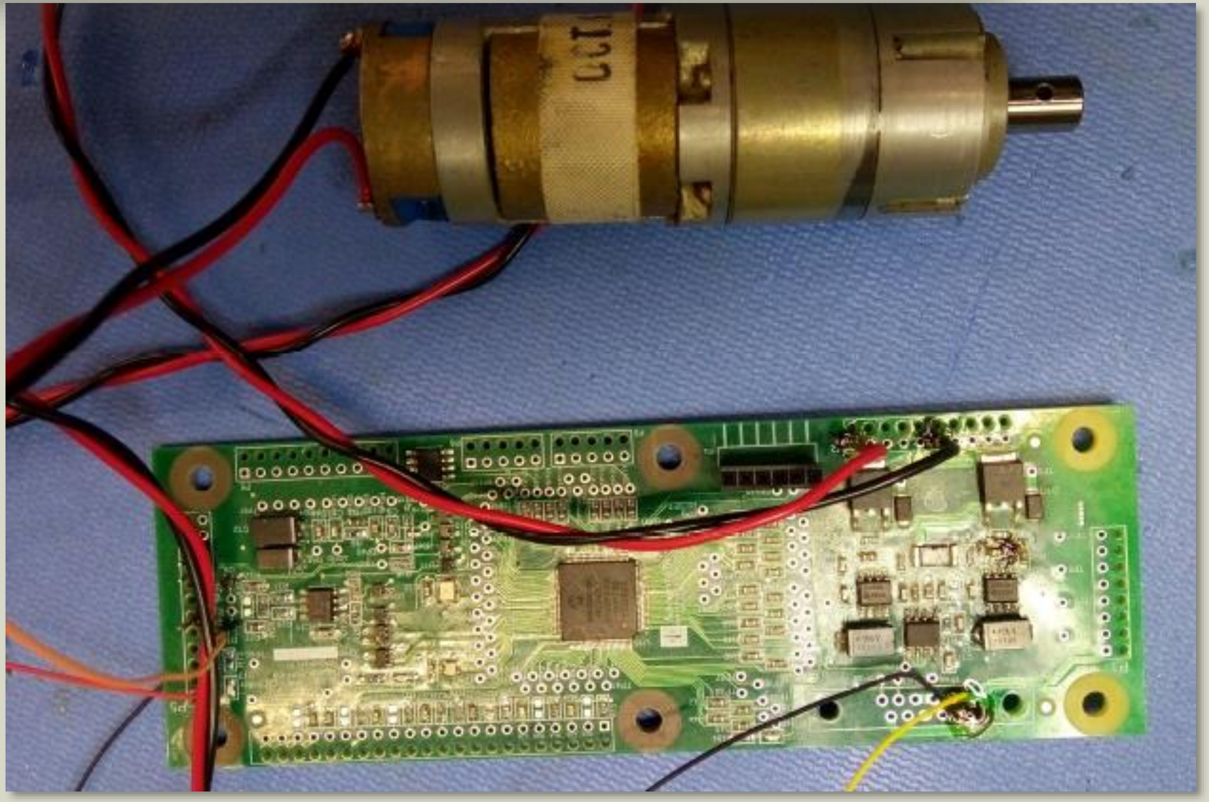

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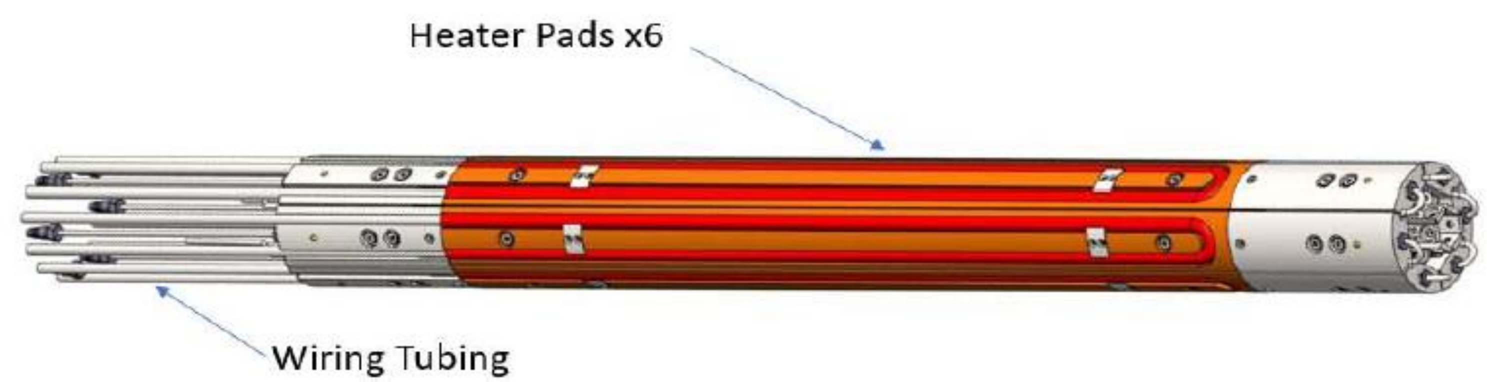
RESPEC

FUTURE PLANS

- Within Project:
  - Finish building near-commercial prototype tool (2022 Q4)
  - Complete prototype tool functionality testing in the small-scale field environment (2023 Q1)
  - Demonstrate prototype tool capabilities in large-scale field borehole (2023 Q2 & Q3)
- 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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APPENDIX

ORGANIZATION CHART

- RESPEC: Project management, modeling, lab testing, field testing
- LBNL: Modeling, lab testing
- UW: Lab testing
- Integrity Insitu: Downhole tool design and construction
- SURF: Small-scale field testing facility
- Range Resources: Large-scale borehole demonstration access

ORGANIZATION CHART

U.S. DEPARTMENT OF ENERGY

PRINCIPAL INVESTIGATOR
Jay Nopola, PE, PG, CPG, RESPEC

ADMINISTRATION, RESPEC
- Business/Contracts Officer
- Finance Officer
- Scheduling Specialist

TECHNICAL ADVISORY COMMITTEE
- **Thomas Doe, PhD,** consultant
- **Herb Wang, PhD,** UW
- **Timothy Kneafsey, PhD,** LBNL
- **Daniel Moos, PhD,** consultant

ENGINEERING AND CONSTRUCTION
- Integrity Insitu
- RESPEC

NUMERICAL MODELING AND SIMULATION
- **Jonny Rutqvist, PhD,** LBNL
- **Samuel Voegeli,** RESPEC

LABORATORY TESTING
- **Hiroki Sone, PhD,** UW
- **Seiji Nakagawa, PhD,** LBNL
- **Stuart Buchholz,** RESPEC

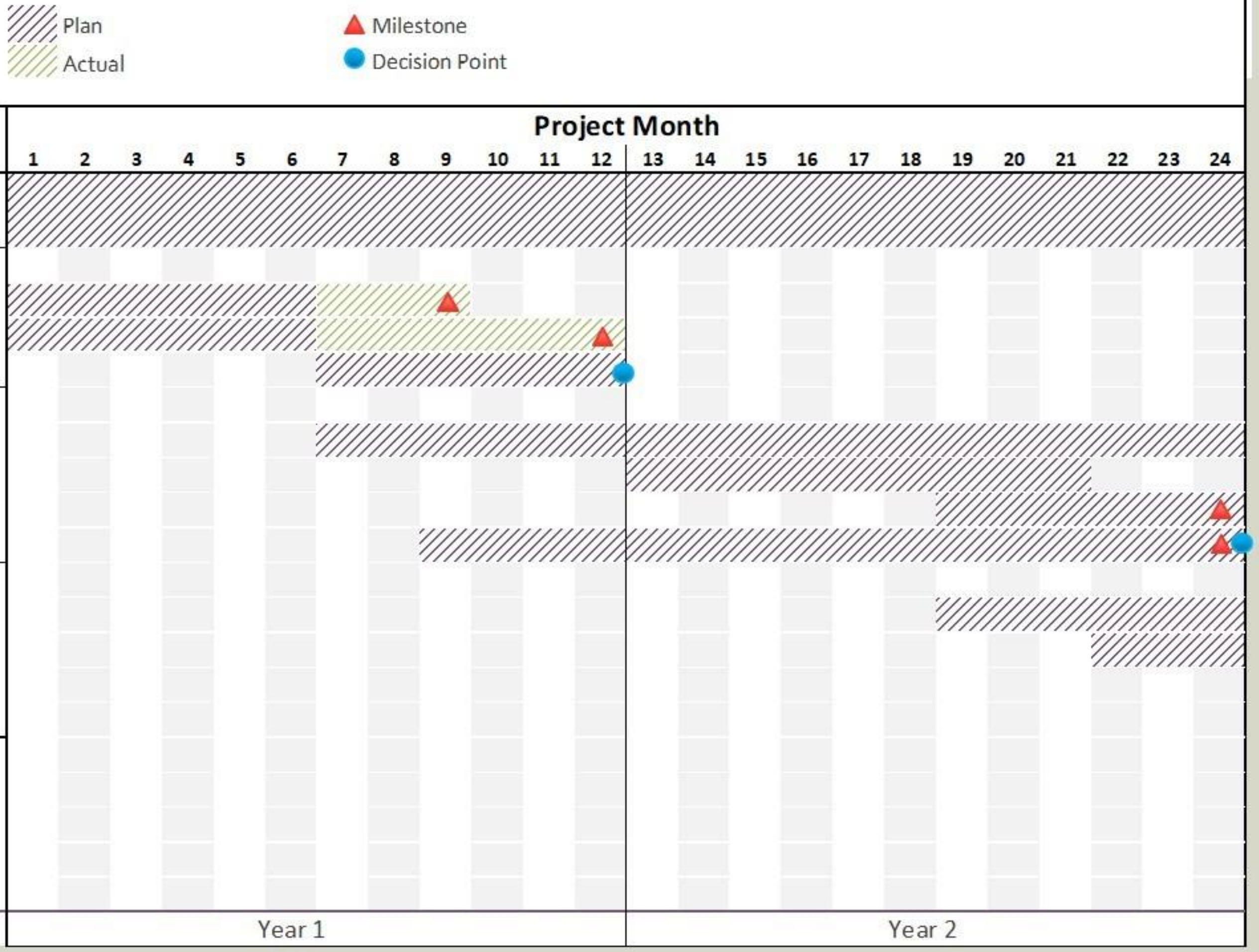
SURF FIELD TESTING
- **Bryce Pietzyk, PE,** SDSTA
- RESPEC
- UW
- LBNL

DEEP WELL FIELD TESTING
- Well Owner
- Drilling Subcontractors
- Integrity Insitu
- RESPEC

GANTT CHART – YEARS 1 AND 2

Thermal Breakout Schedule

Task	ACTIVITY	Responsible Lead	Pertinent Team Resources	PLAN START	PLAN DURATION
1	Project Management/Planning, Administration, and Technical Advisory Committee	RESPEC		1	48
2	Engineering Design and Numerical Modeling				
2.1	Initial Numerical Modeling	RESPEC	LBNL	1	6
2.2	Initial Engineering Design Requirements	RESPEC	BHGE, TAC	1	6
2.3	Modeling Evaluation of Subsurface Factors	RESPEC	LBNL	7	6
3	Laboratory Testing				
3.1	True-Triaxial Borehole Breakout Tests	UW		7	18
3.2	Shaped Core Uniaxial Tests	LBNL	UW	13	9
3.3	Shaped Core Thermal-Poromechanics Tests	RESPEC	LBNL	19	6
3.4	Confirmation Modeling	RESPEC	LBNL	9	16
4	SURF Field Testing				
4.1	Prototype Tool Design and Construction	RESPEC	BHGE, TAC	19	12
4.2	Safety and Access	SURF	TEAM	22	15
4.3	Field-Scale Testing	RESPEC	TAC, UW, LBNL	25	12
4.4	Confirmation Modeling	RESPEC	LBNL	25	12
5	Deep Well Field Testing				
5.1	Prototype Tool Design and Construction	RESPEC	BHGE, TAC	31	9
5.2	Safety and Access	TBD	TEAM	38	6
5.3	Field-Scale Testing	RESPEC	BHGE, TAC	40	4
5.4	Confirmation Modeling	RESPEC	LBNL	44	6



GANTT CHART – YEARS 3 AND 4

Thermal Breakout Schedule

Task	ACTIVITY	Responsible Lead	Pertinent Team Resources	PLAN START	PLAN DURATION
1	Project Management/Planning, Administration, and Technical Advisory Committee	RESPEC		1	48
2	Engineering Design and Numerical Modeling				
2.1	Initial Numerical Modeling	RESPEC	LBNL	1	6
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