Development of thermal breakout technology for determining in situ stress

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Jay Nopola, RESPEC (jay.nopola@respec.com)

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August 26-30, 2019

Discussion Topics

- Introduction
- Technical Status
- Accomplishments to Date
- Lessons Learned
- Synergy Opportunities
- Project Summary

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- **Introduction**
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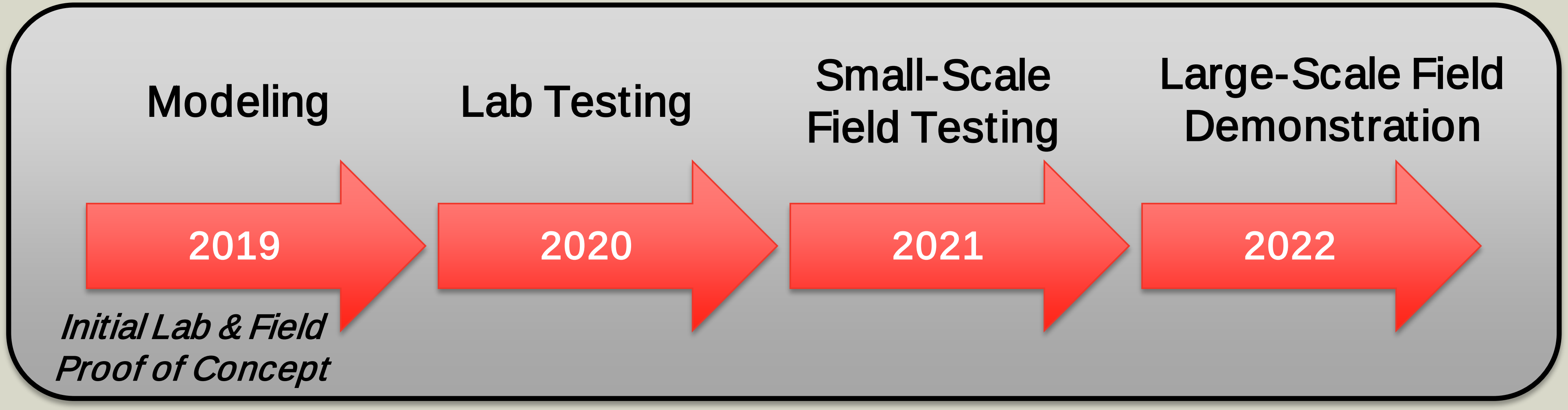
Introduction

- Use well-established, existing technology to improve the standard methods of in situ stress measurements by including thermally induced borehole breakout technology
- 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



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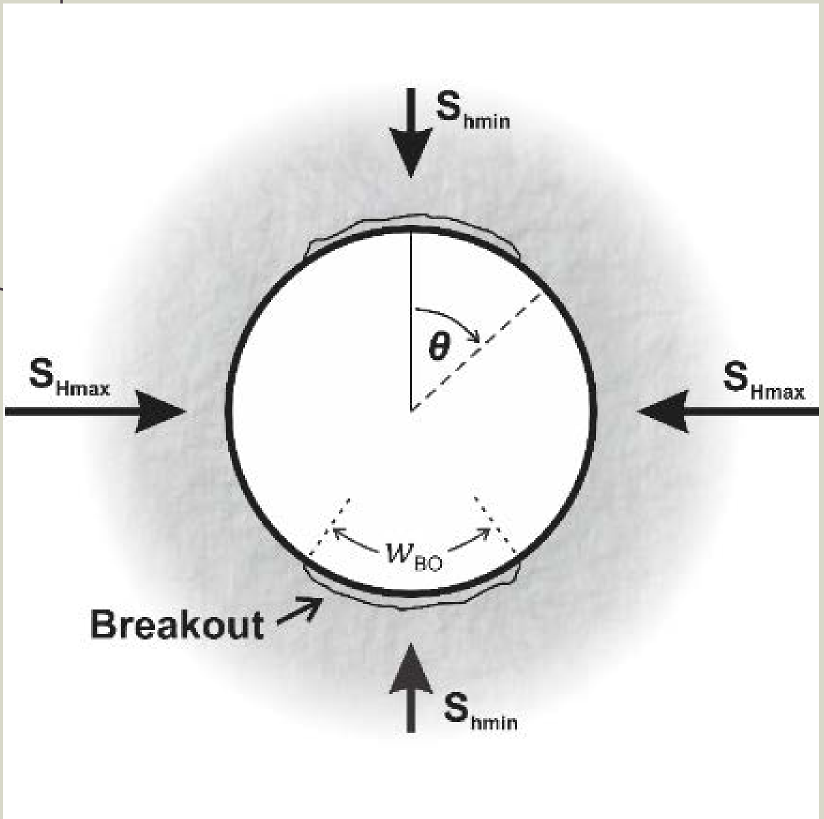
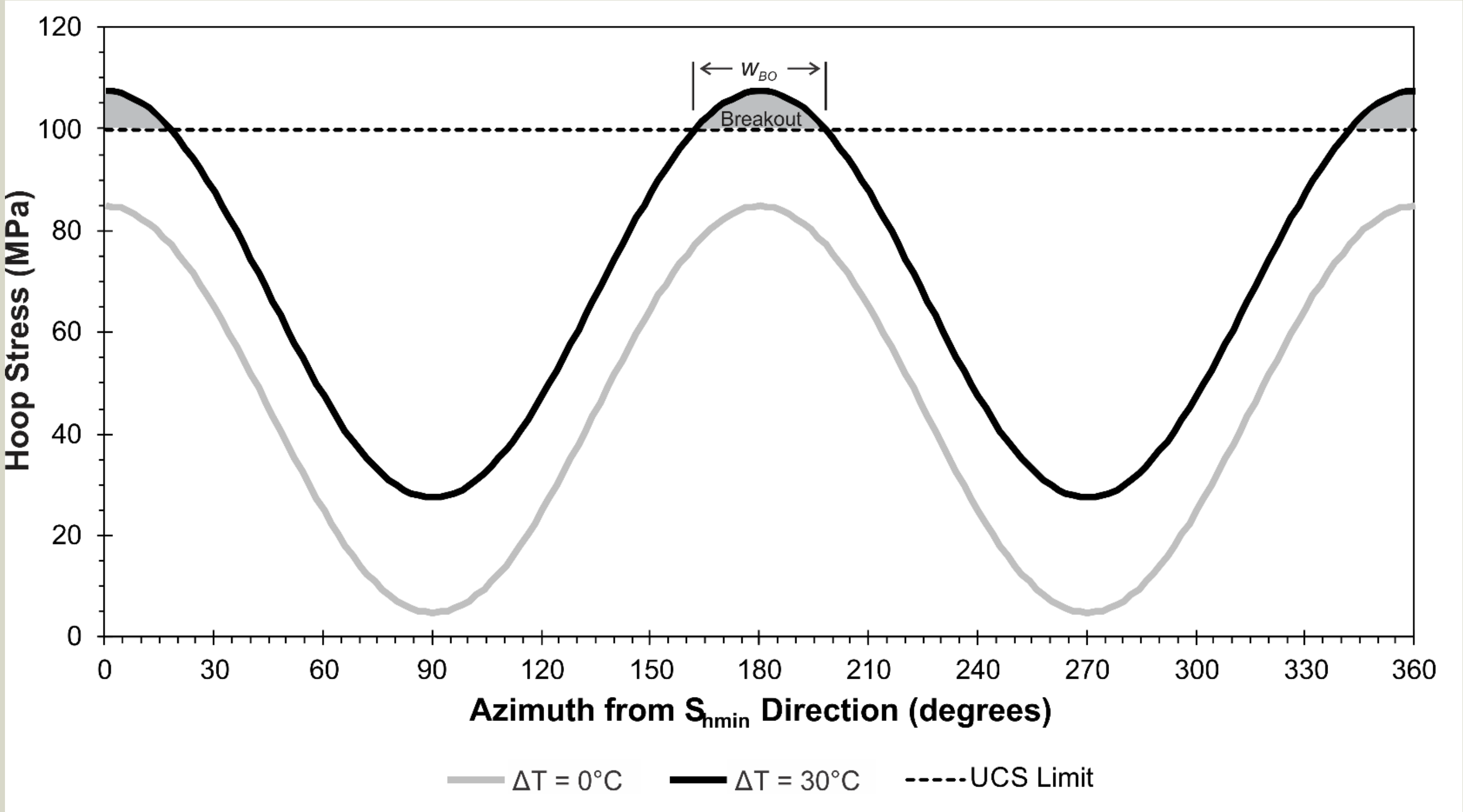
Technical Status – Modeling

› **Theoretical proof of concept**

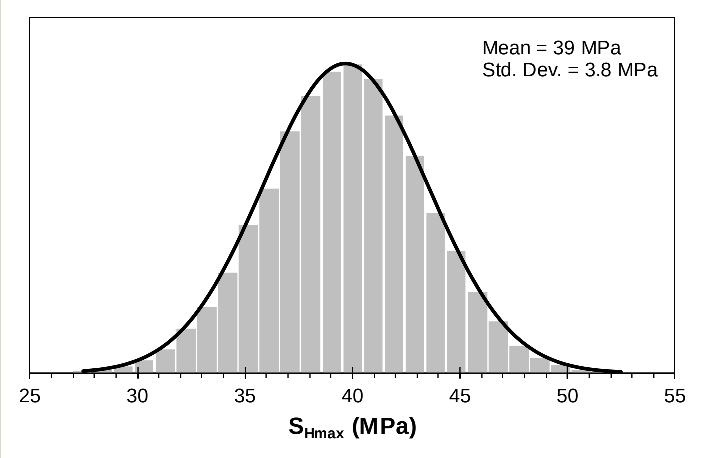
$$\sigma_{\theta\theta} = S_{\text{hmin}} + S_{\text{Hmax}} + 2\left(S_{\text{Hmax}} - S_{\text{hmin}}\right)\cos 2\theta - P_0 - P_m + \frac{\alpha_t E \Delta T}{1-\nu}$$

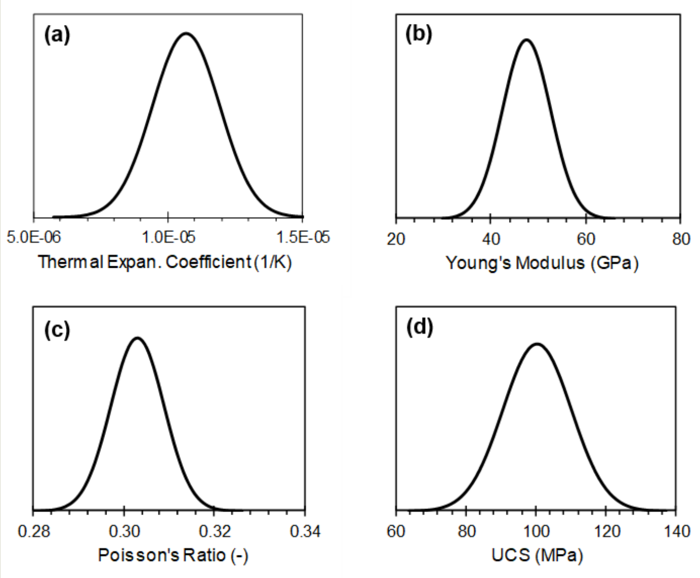


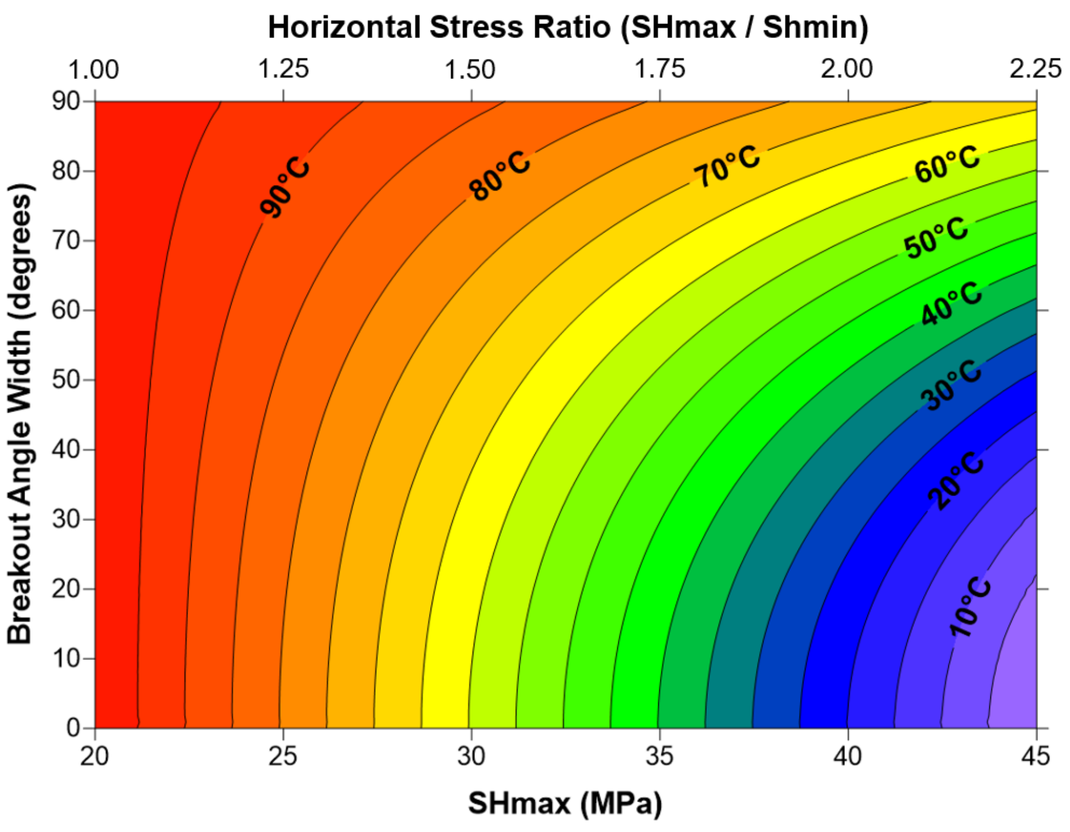


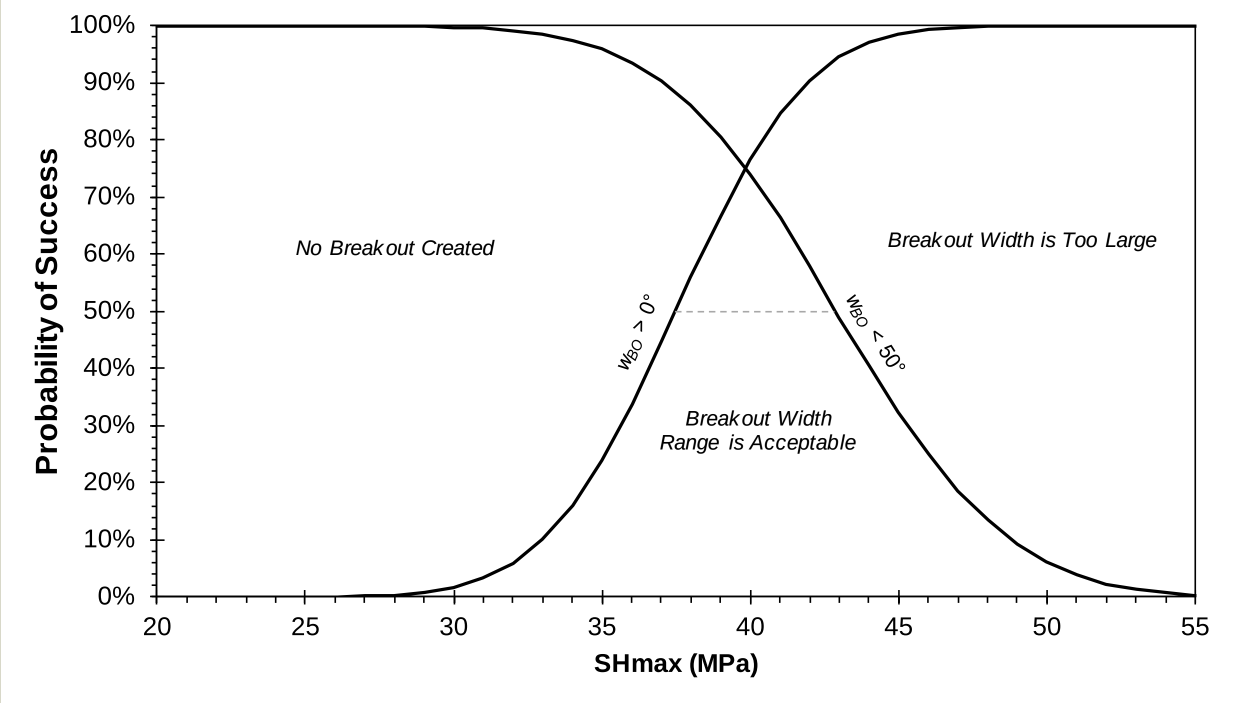
Technical Status – Modeling

› Statistical analysis



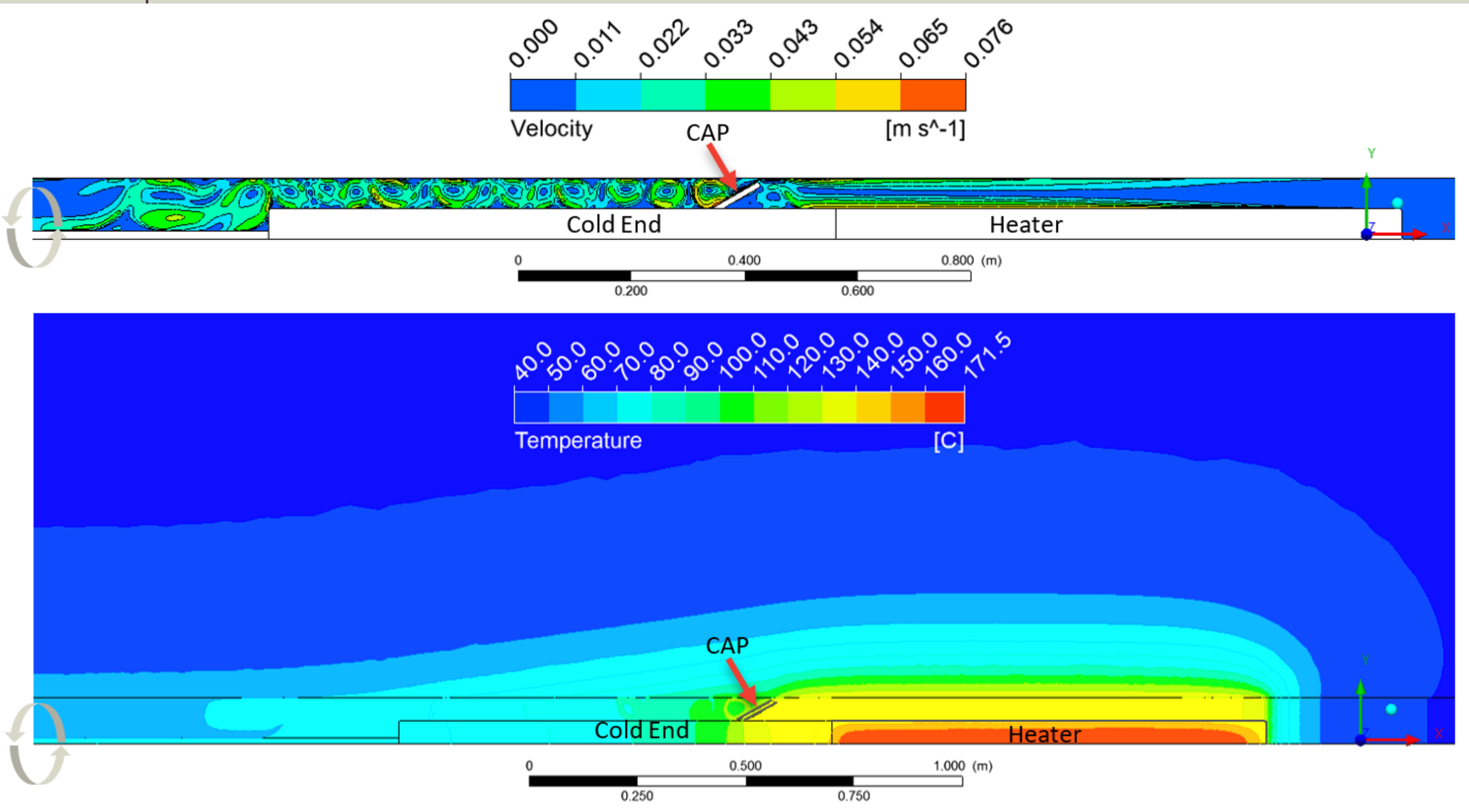


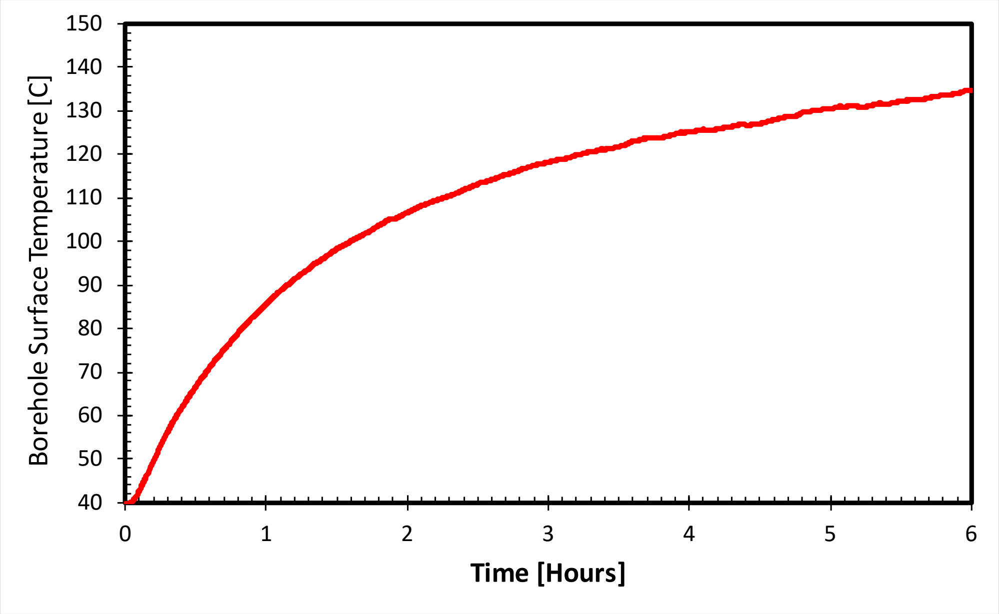


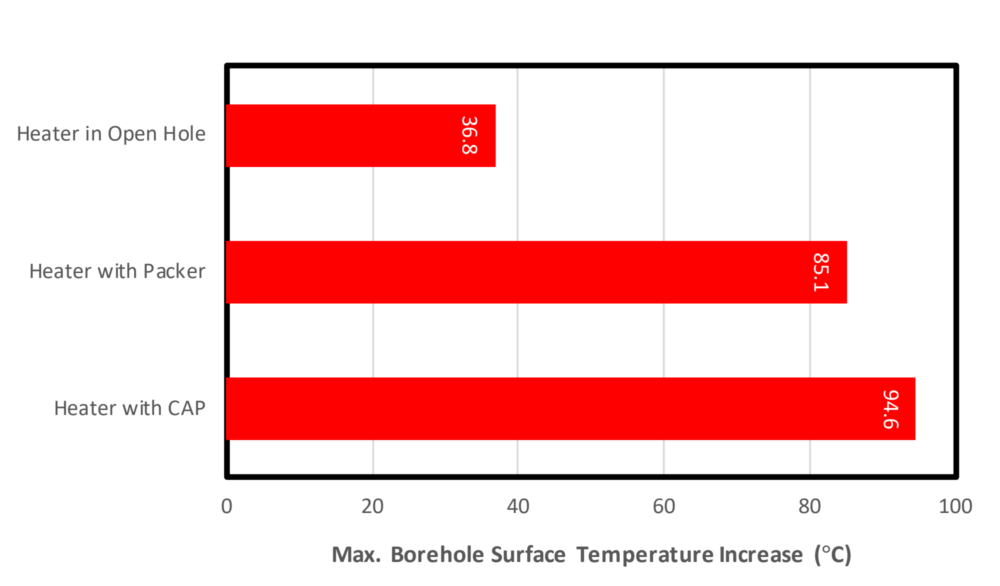


Technical Status – Modeling

- Computational fluid dynamics simulation of heat transfer

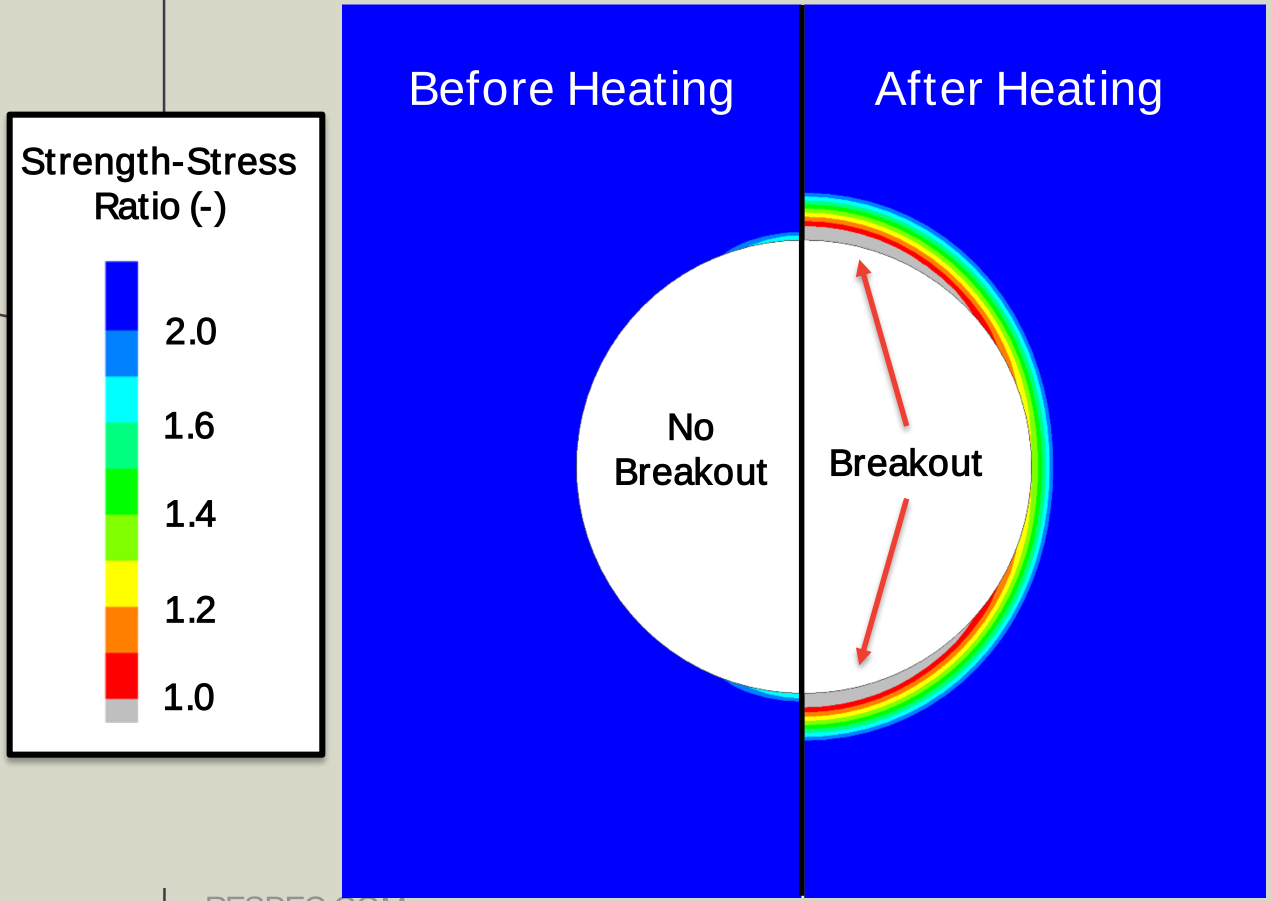


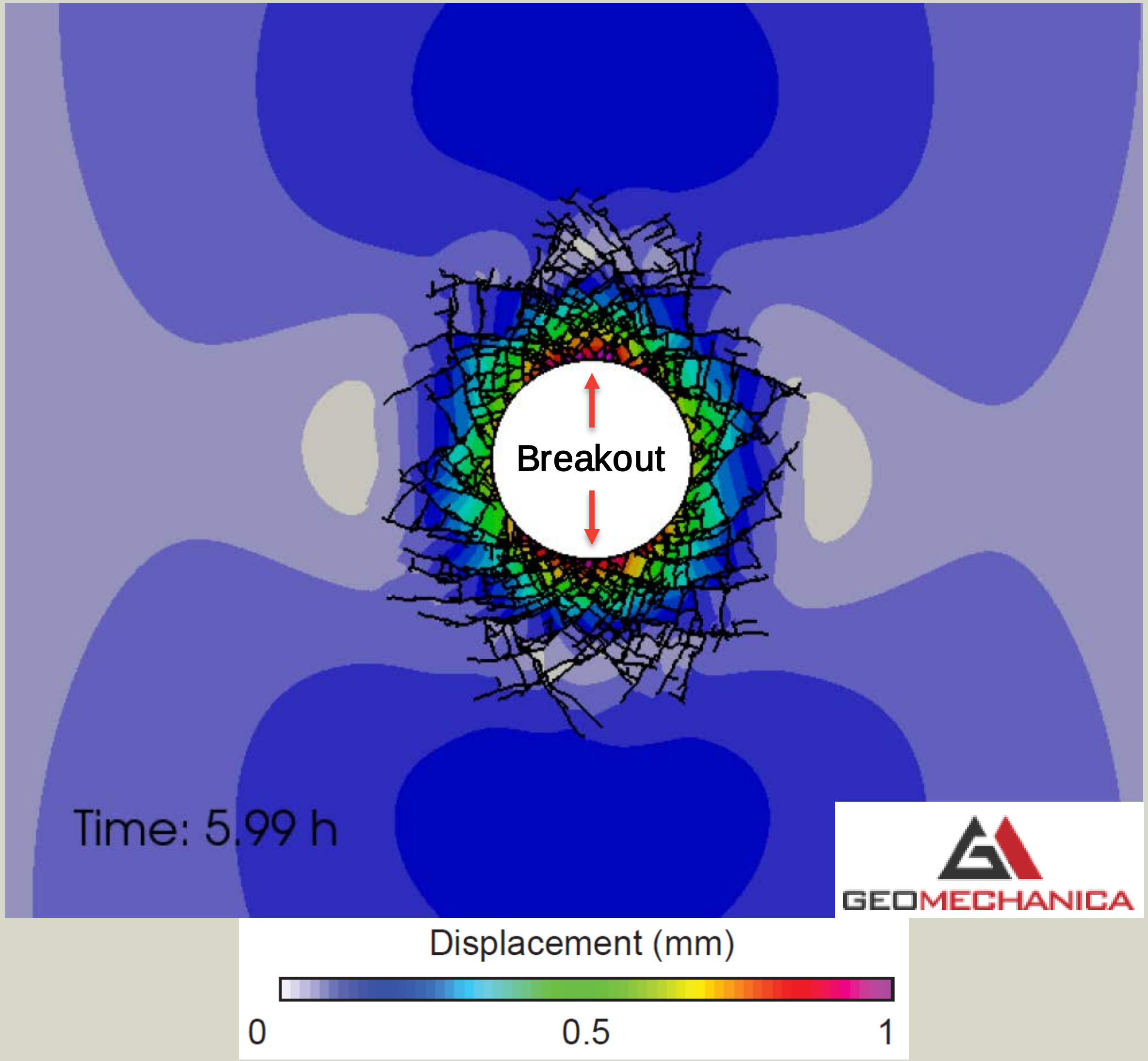




Technical Status – Modeling

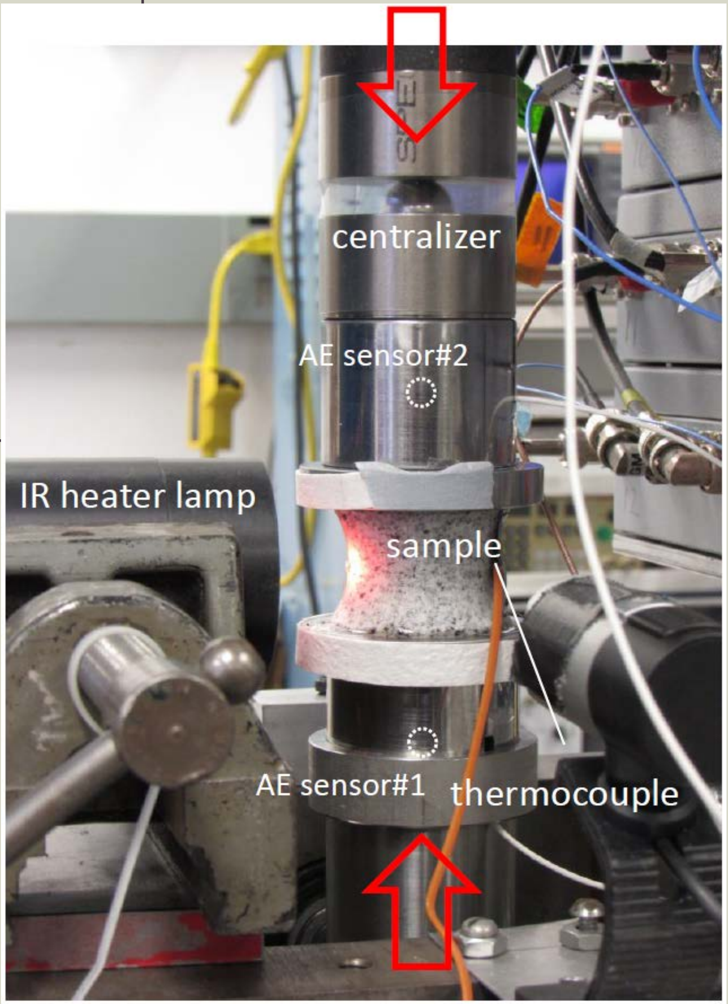
- Thermal-mechanical (TM) simulations

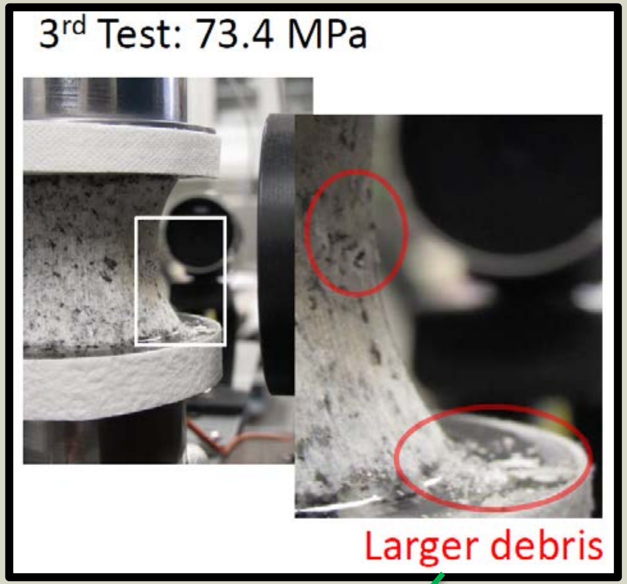


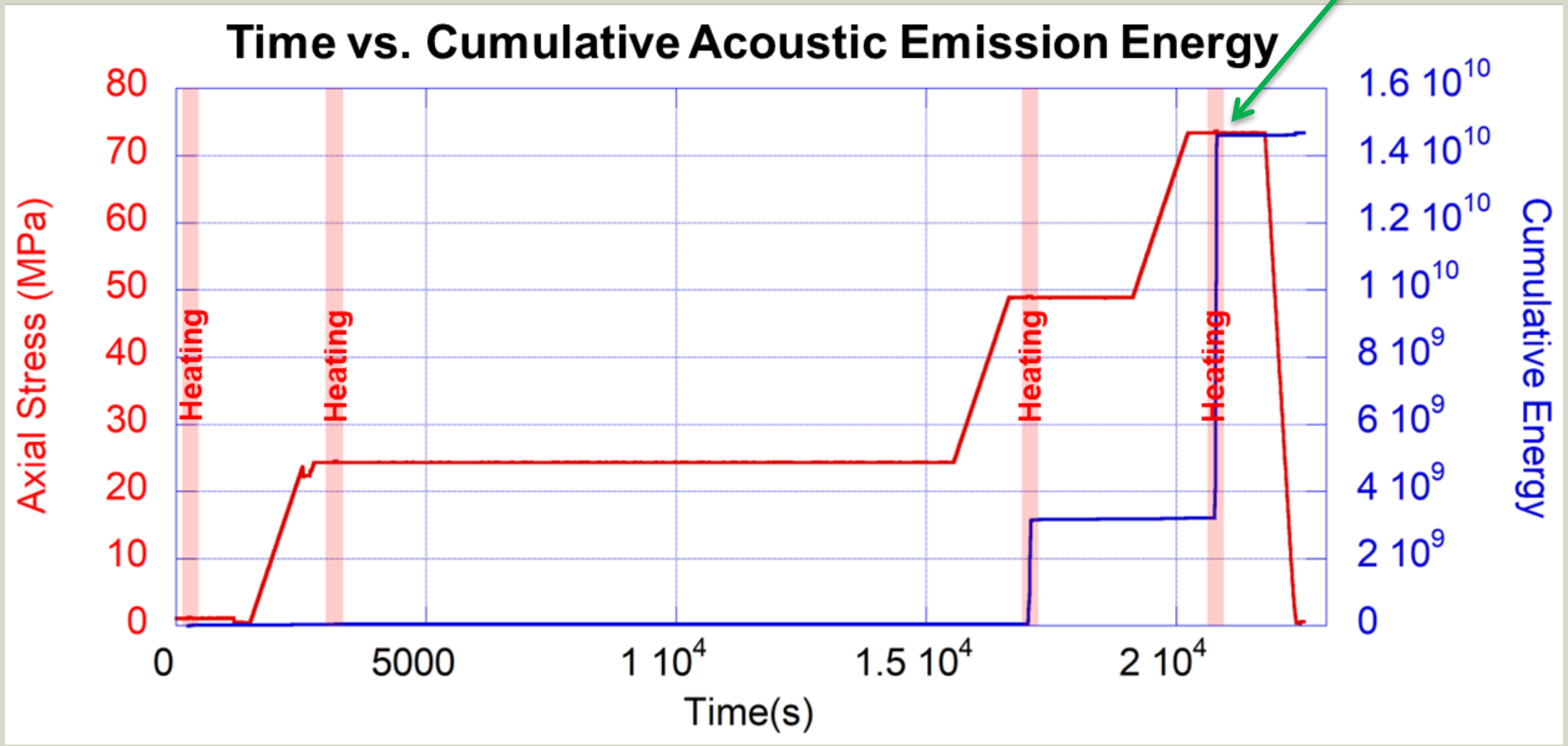


Technical Status – Lab

› Laboratory proof of concept

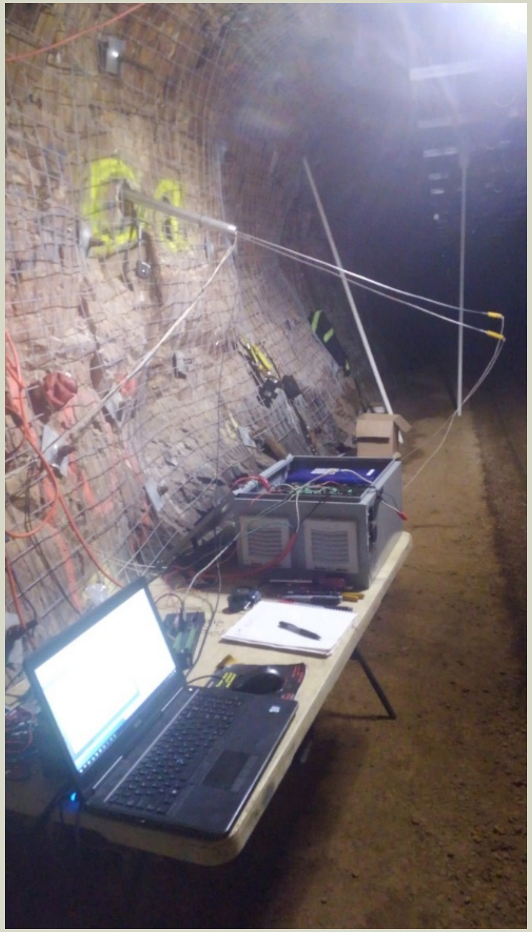


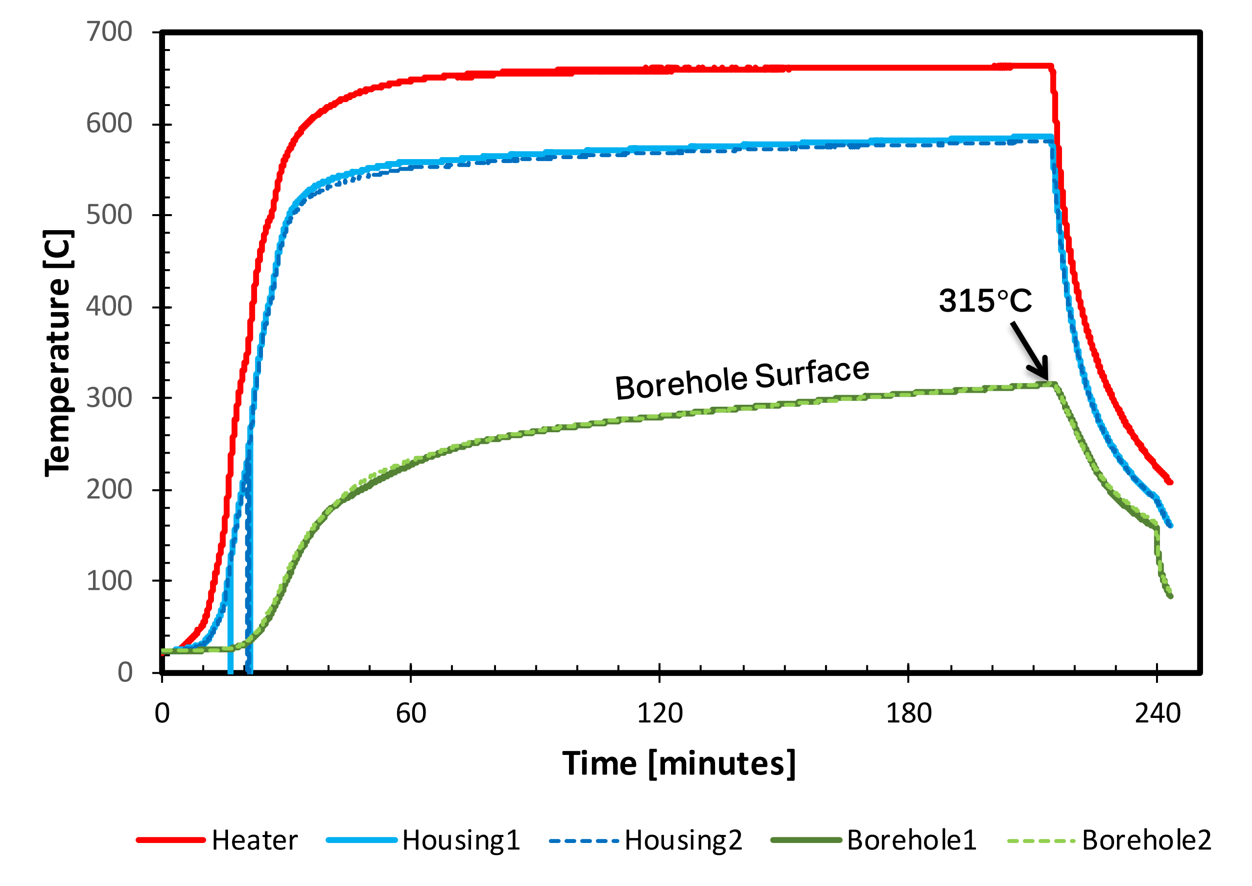




Technical Status - Field

› Initial field-scale testing at SURF

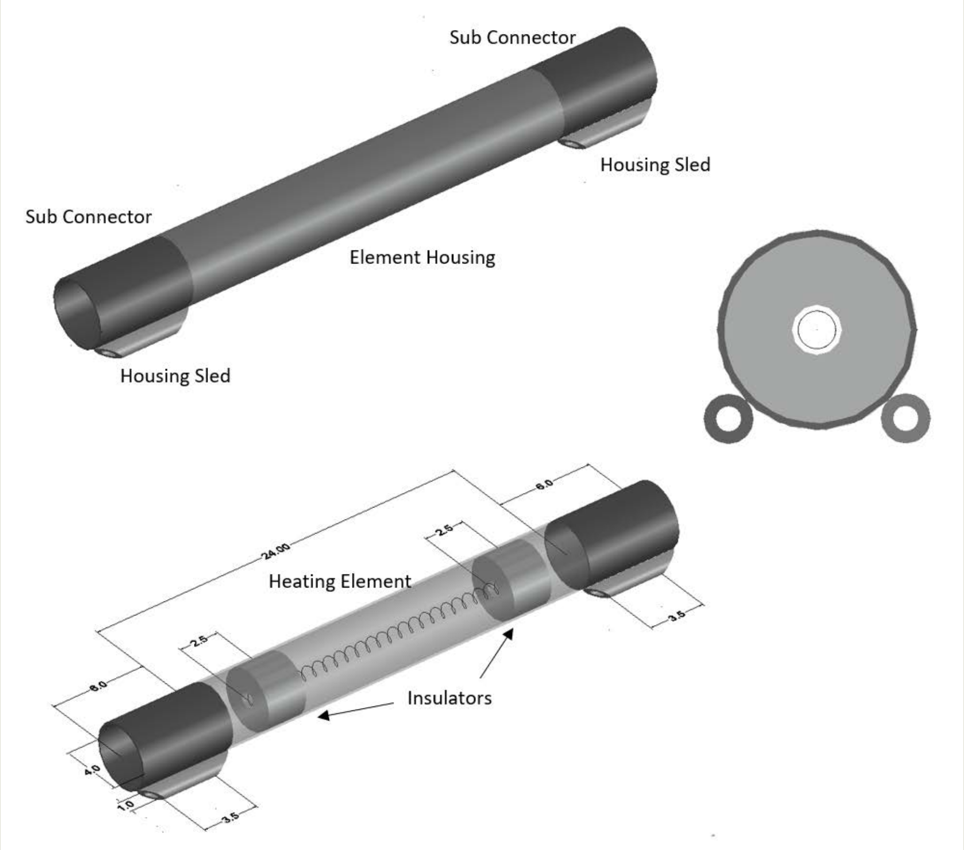




Technical Status – Downhole Tool

› **Conceptual downhole tool design and engineering requirements:**

- Telemetry for downhole communications
- Reasonable power requirements
- Temperatures within operating limits
- Existing tech can be used
- Monitoring system is practical



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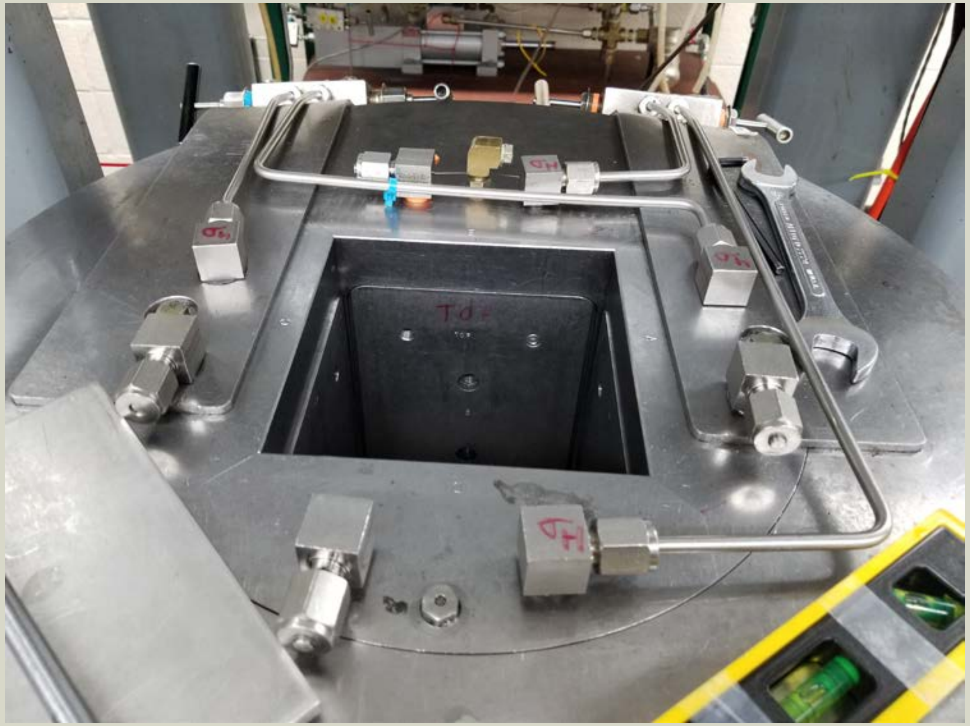
Accomplishments to Date

- Established Technical Advisory Committee (TAC)
- Initial laboratory proof of concept achieved
- Analytical and numerical thermomechanical modeling confirms theoretical concept
- CFD modeling indicated adequate power requirements and efficiency
- Successful deployment and operation of prototype…300°C borehole temperatures in 3 hours
- Upgraded University of Wisconsin – Madison polyaxial machine for acoustic emissions (AE) monitoring
- Identified multiple feasible options to satisfy downhole tool engineering requirements



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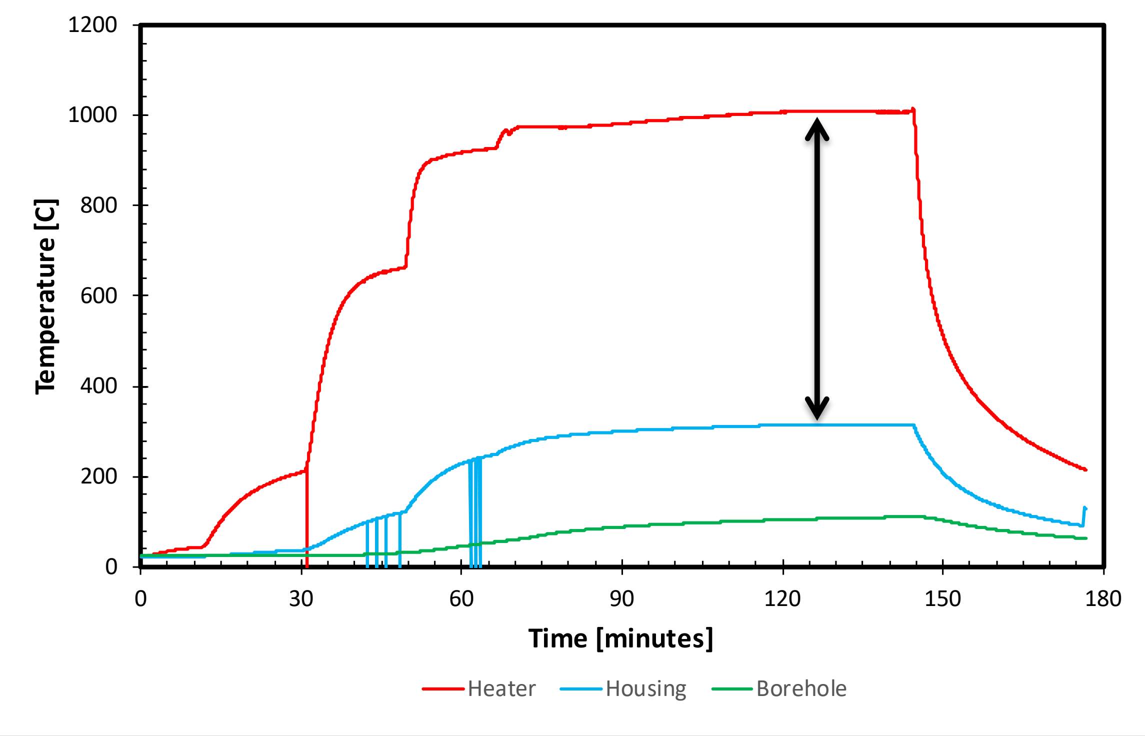
Lessons Learned

- Anticipate some partnering/contracting issues
- Benefits of preliminary but simple tests for initial proof of concept/learning
- Heater housing material – consider all heat transfer mechanisms
- Adequate power source – voltage drop
- Need to be aware of deviations between modeling and reality
- Better understanding of the applicability of the concept



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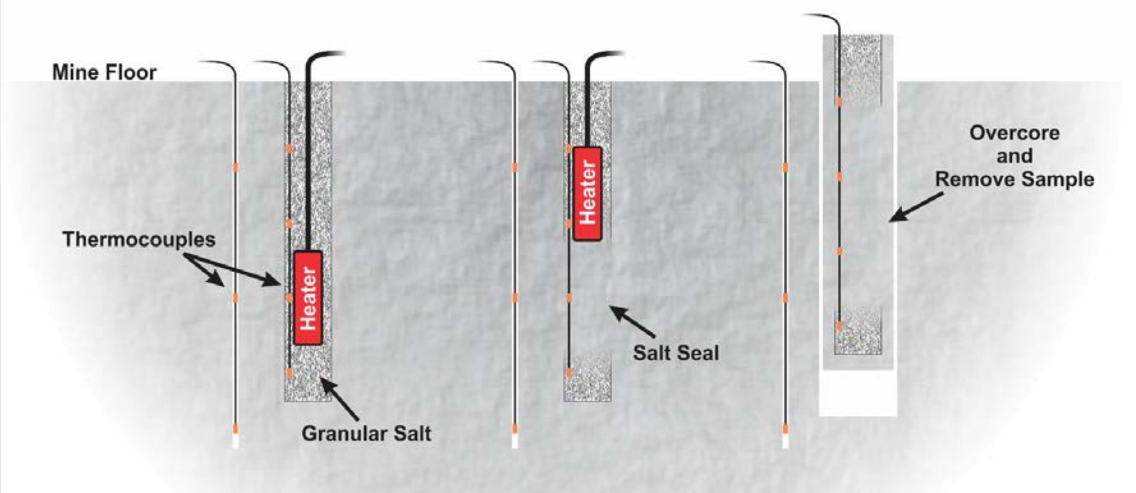
Synergy Opportunities

- Awarded SBIR project for thermally activating salt
- Proposed DOE Geothermal Technologies Office FOA-0002083 for a related thermal measurement concept for in situ stress
- Integrity Insitu interested in included thermal breakout tech
- EGS Collab and kISMET activities at SURF
- Interest from mining sector for collaboration project



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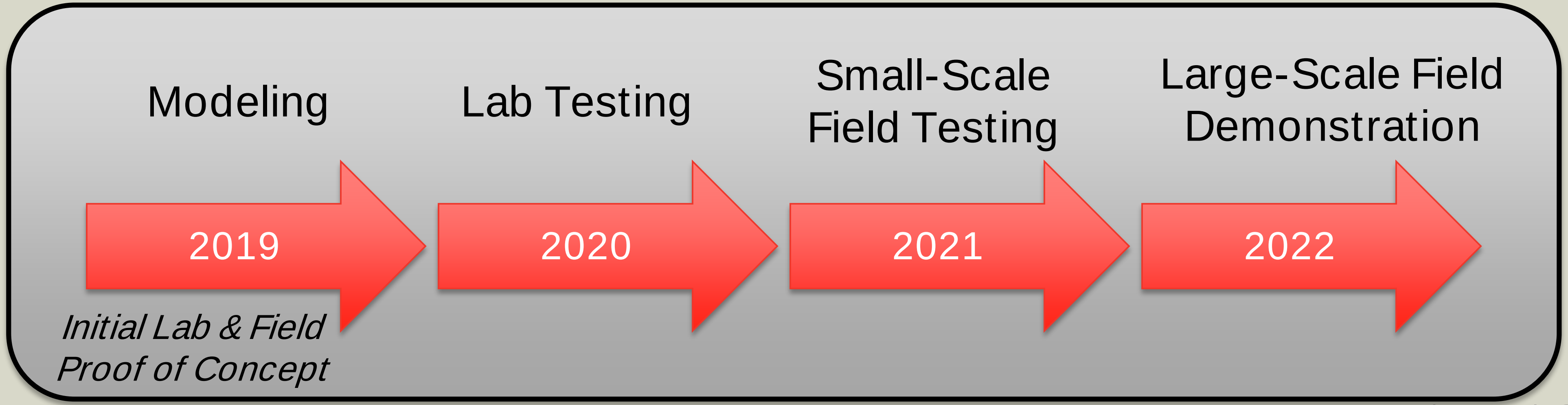
Project Summary

- **Key Findings:**
  - We can break rock with heat
    - Target temperatures can be realistically achieved
  - Analytical and numerical results agree on applicability and resolution
- **Next Steps:**
  - Lab testing to tie all of the modeling together under controlled conditions



Acknowledgements

- Thomas Doe
- Daniel Moos

- Stephen Henry - NETL

APPENDIX

Benefit to the Program

- **Program goal:**
  - Improve the measurement and reduce the uncertainty in the measurement of in-situ maximum principal stress in the deep subsurface

- **Program benefit:**
  - Better understand the geomechanical impacts of CO_2 sequestration and reduce the risks associated with those impacts

Project Overview

- **Budget Period 1: Modeling**
  - Perform initial numerical modeling to support the proof-of-concept in a range of subsurface conditions.
  - Expand the numerical modeling to guide the proposed laboratory-testing program.
  - Define the engineering requirements for downhole tool development.
- **Budget Period 2: Laboratory Testing**
  - Produce a matrix of laboratory test results that support the determination of the maximum compressive strength through thermally induced stress changes.
  - Refine the numerical modeling approach, if necessary.
  - Develop and test breakout instrumentation techniques.
  - Provide specific outstanding objectives to validate during field testing.

Project Overview

- **Budget Period 3: Small-Scale Field Testing**
  - Build and deploy small-scale prototypes of the system in a downhole environment.
    - Validate the concept in an area where additional monitoring is possible in adjacent boreholes.
  - Define any specific outstanding objectives to validate during the full-scale deep well testing.
- **Budget Period 4: Large-Scale Borehole Demonstration**
  - Demonstrate a successful test in a deep well.
  - Compare the results of the thermal breakout technology against the existing state-of-the-art for the same deep well.
  - Provide validation for commercializing and adopting the technology.

Organization Chart

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

Organization Chart

U.S. DEPARTMENT OF ENERGY

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

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

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

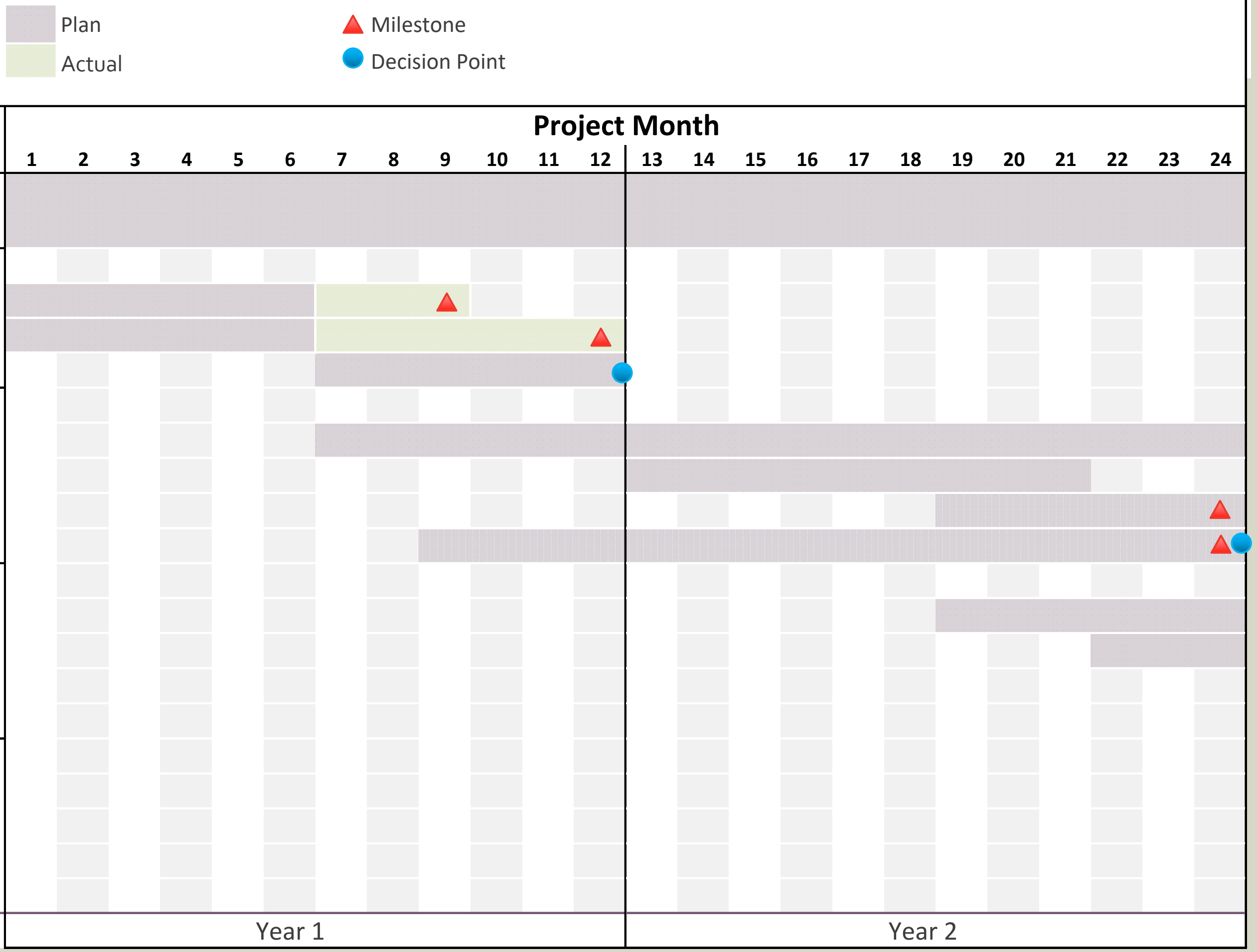
SURF FIELD TESTING
- **Bryce Pietzyk, PE,** SDSTA
- RESPEC
- UW
- LBNL

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



RESPEC

Gantt Chart – Years 3 and 4

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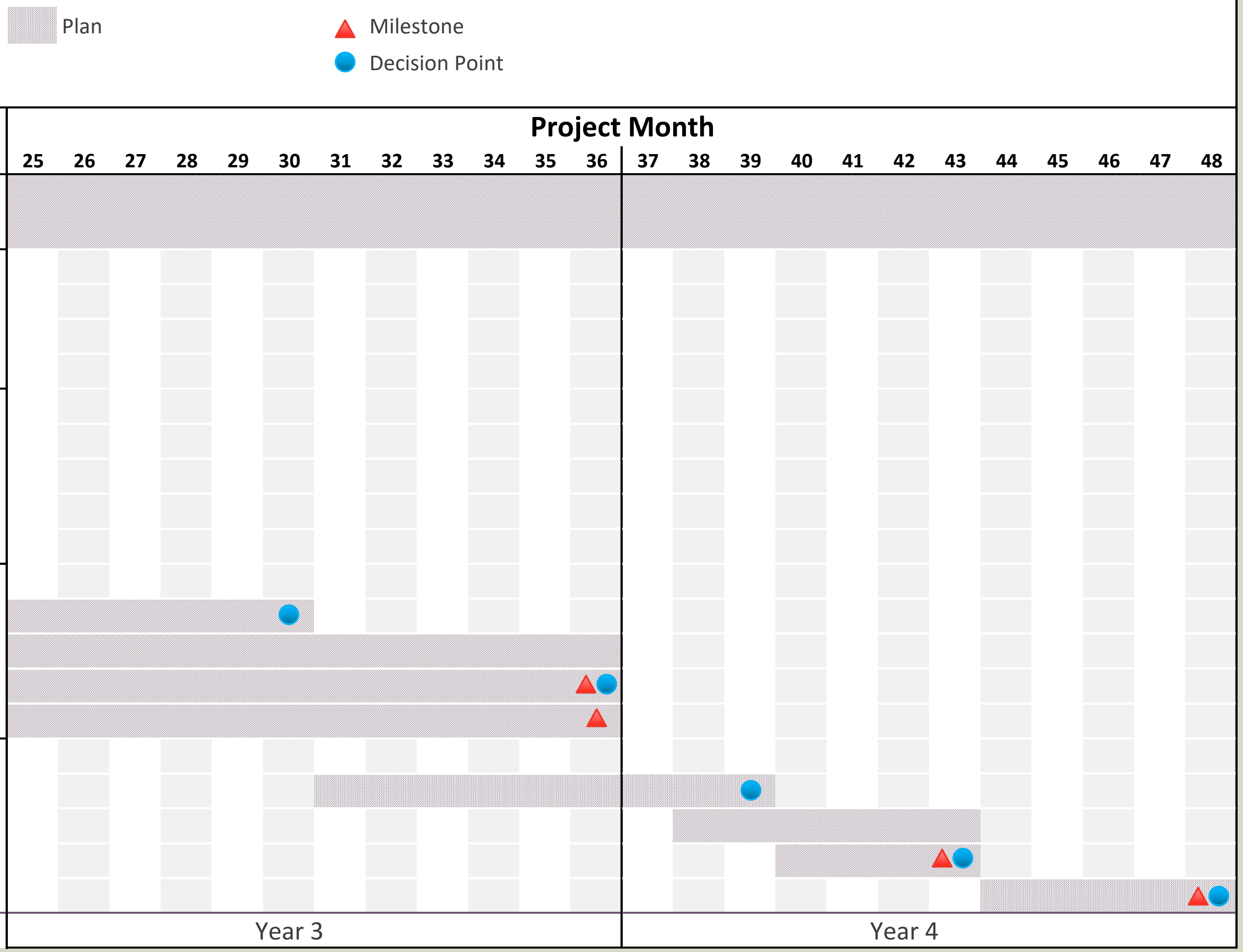

Bibliography

› Voegeli, S., Nopola, J., Yang, G., Moos, D. and Doe, T., 2019. Deterministic and Statistical Modeling of a New Thermal Breakout Technology for Measuring the Maximum Horizontal In Situ Stress. TBA.*

*Publishing in progress