

DEVELOPMENT OF THERMAL BREAKOUT TECHNOLOGY FOR DETERMINING IN SITU STRESS

Award # DE-FE0031688

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

U.S. Department of Energy National Energy Technology Laboratory Carbon Management and Oil and Gas Research Project Review Meeting – Carbon Storage August 2 - 11, 2021













Thomas Doe Daniel Moos



AGENDA

- INTRODUCTION
- TECHNICAL STATUS
- ACCOMPLISHMENTS TO DATE
- LESSONS LEARNED
- SYNERGY OPPORTUNITIES
- SUMMARY



AGENDA



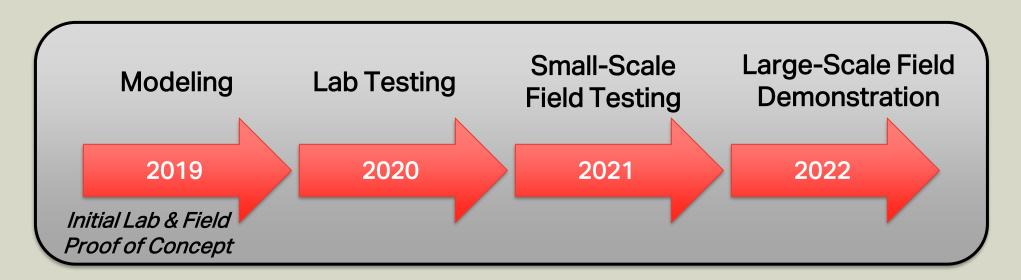
- TECHNICAL STATUS
- ACCOMPLISHMENTS TO DATE
- LESSONS LEARNED
- SYNERGY OPPORTUNITIES
- SUMMARY



INTRODUCTION

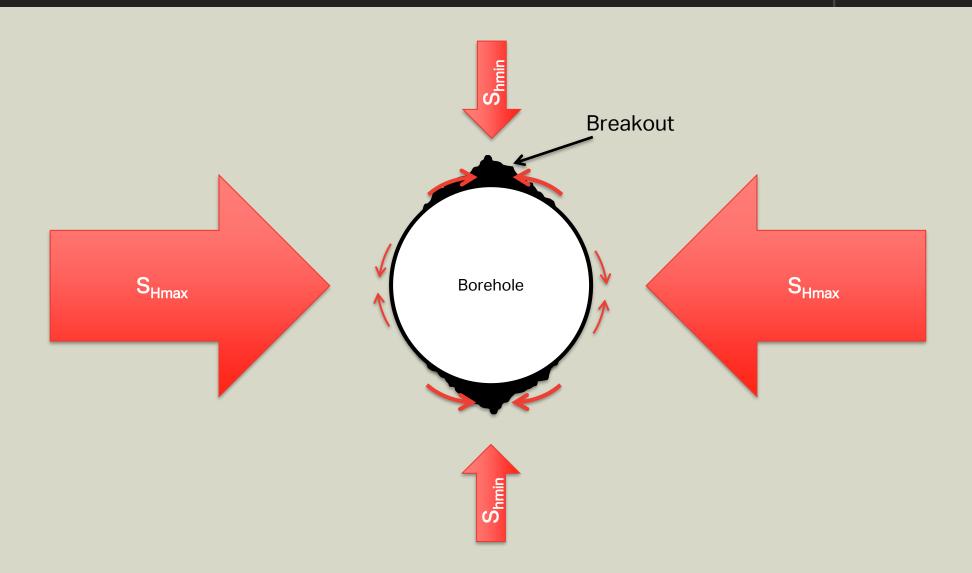


- Use well-established, existing technology to improve the standard methods of in situ stress measurements by including thermally induced borehole breakout technology
- Borehole breakouts are a proven indicator of the maximum horizontal in situ stress magnitude
- The thermal breakout technology is intended to reliably create breakouts by inducing thermal compressive stress



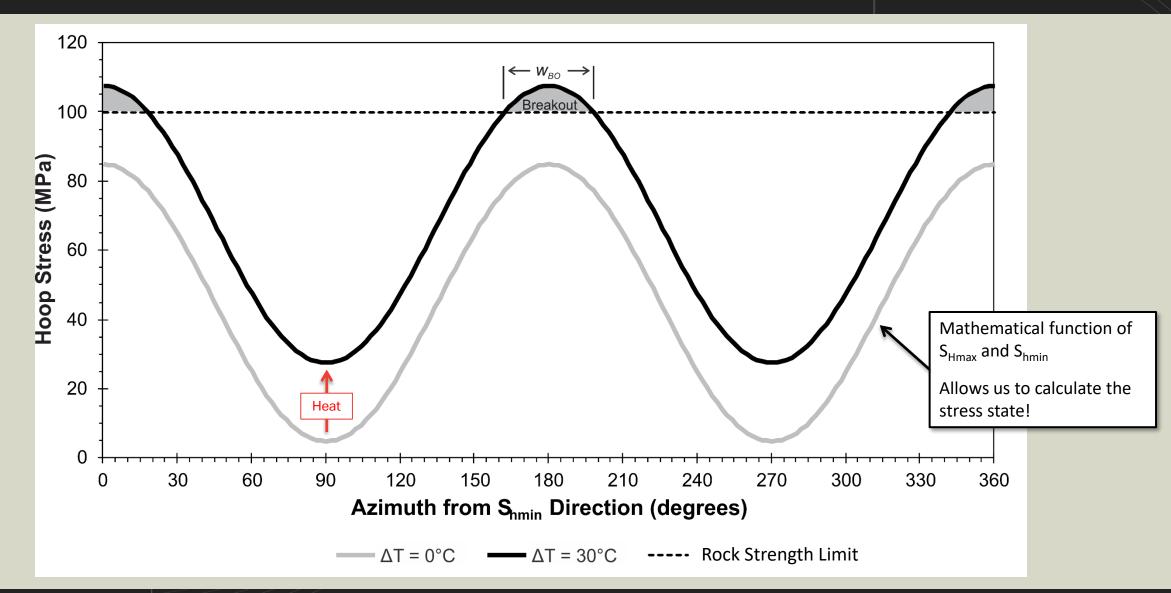
BACKGROUND





BACKGROUND





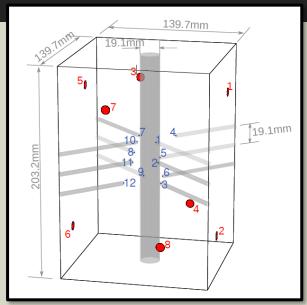
AGENDA

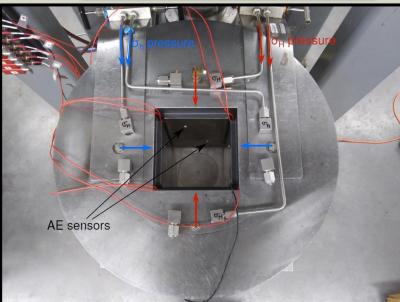


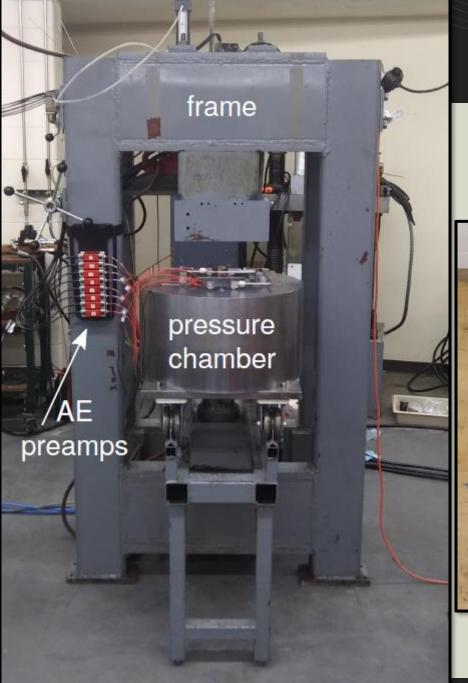
- <u>TECHNICAL STATUS</u>
- ACCOMPLISHMENTS TO DATE
- LESSONS LEARNED
- SYNERGY OPPORTUNITIES
- SUMMARY



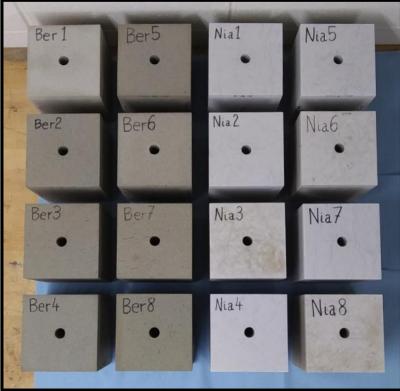




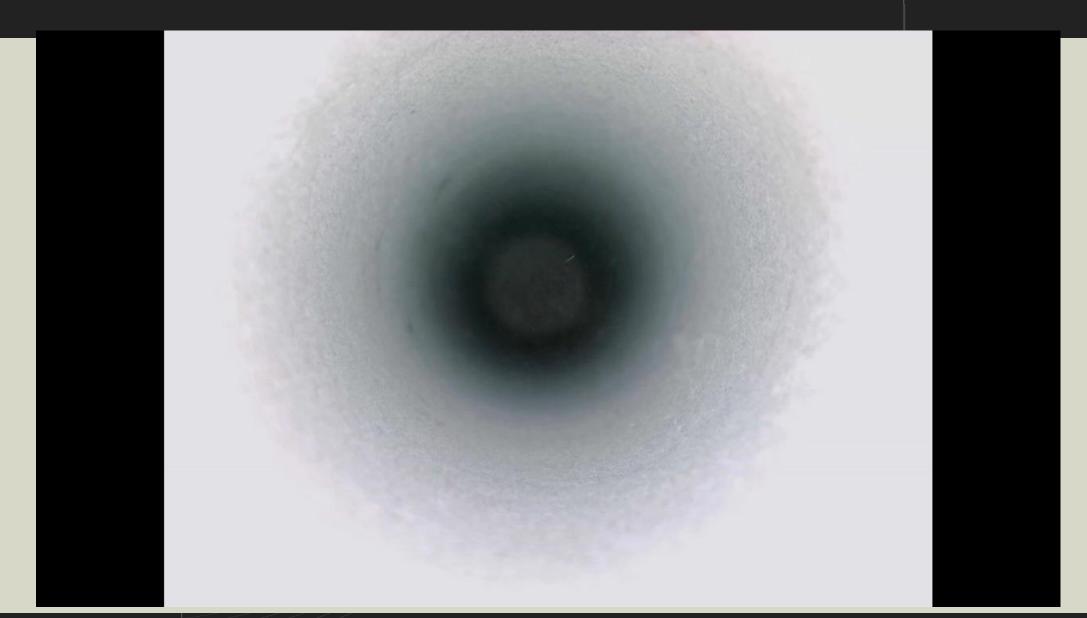




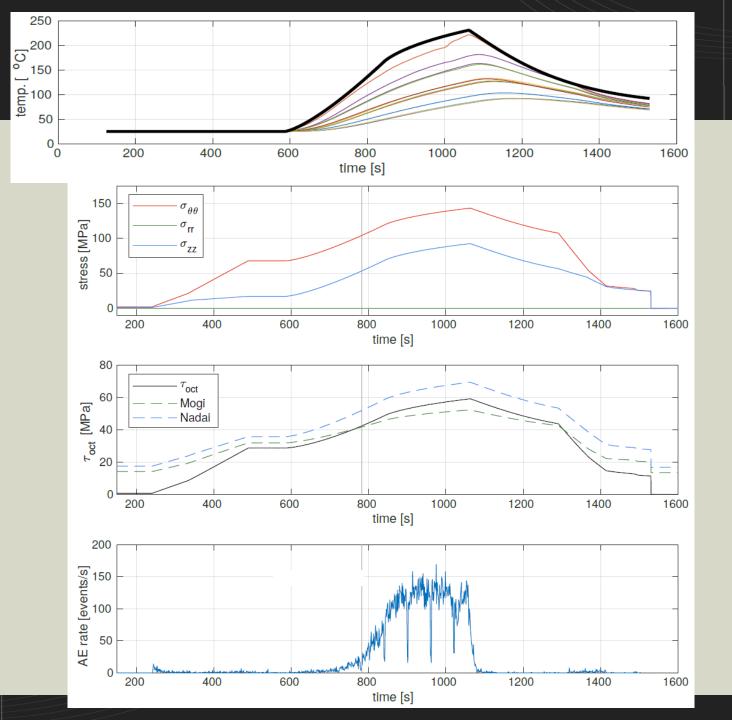




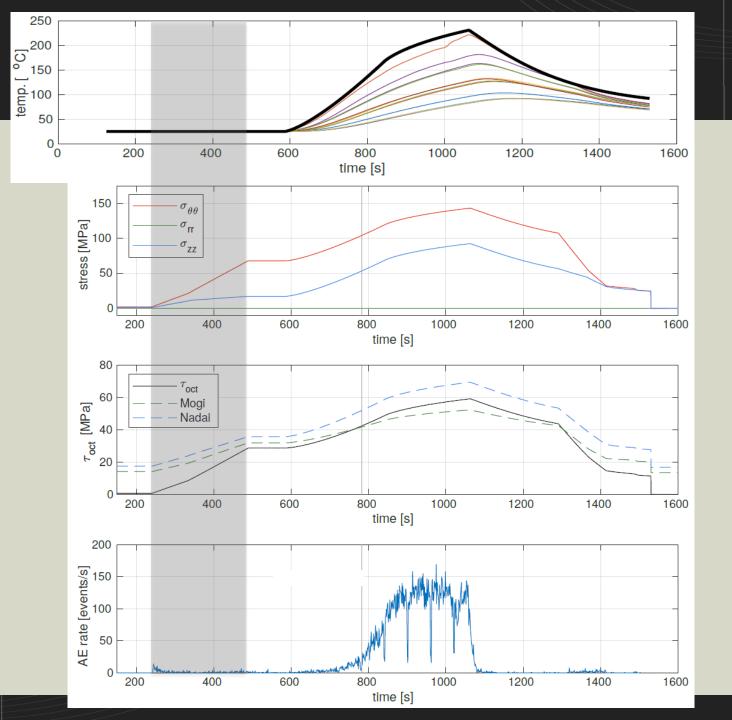




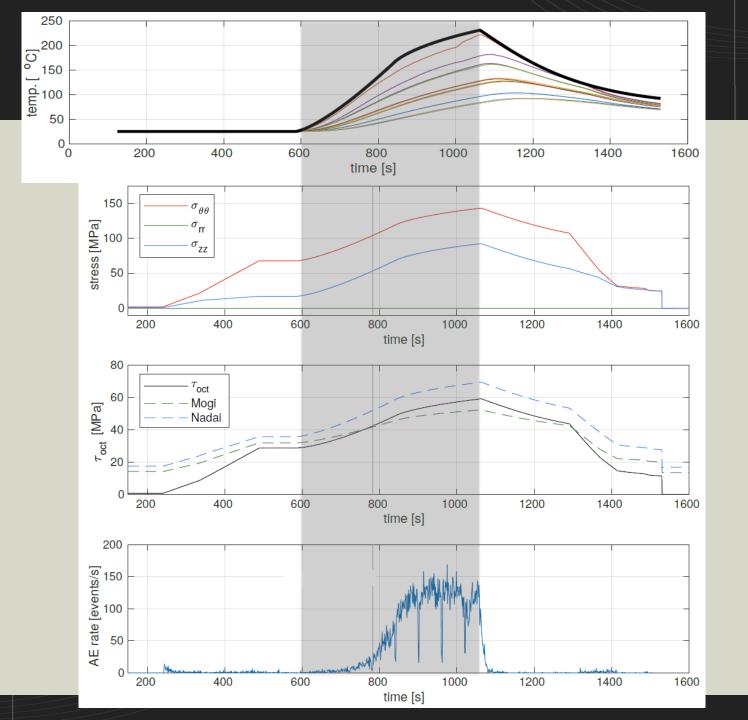




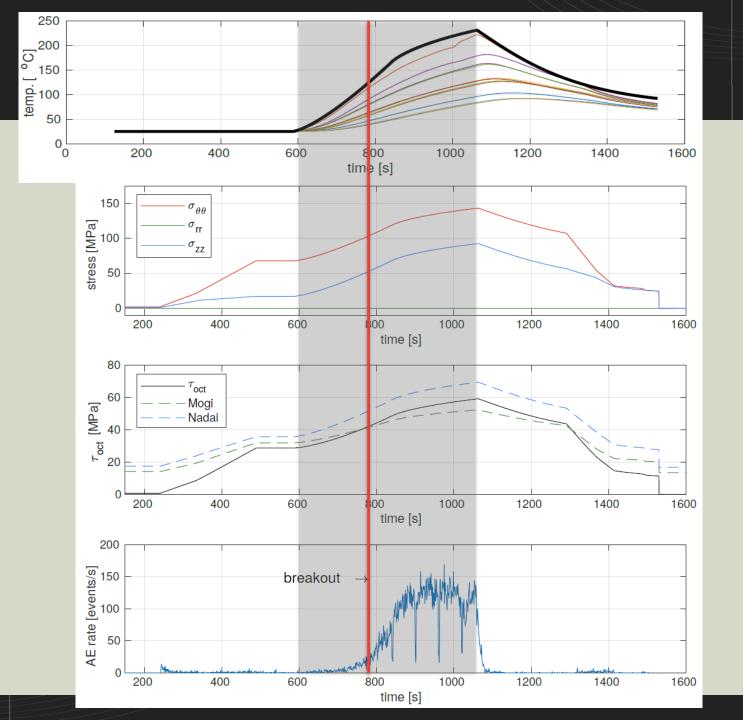




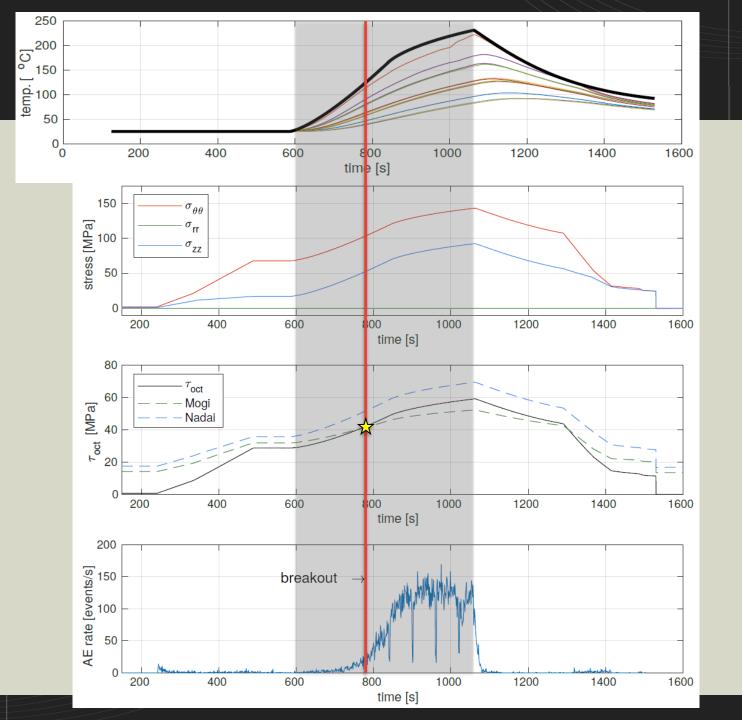






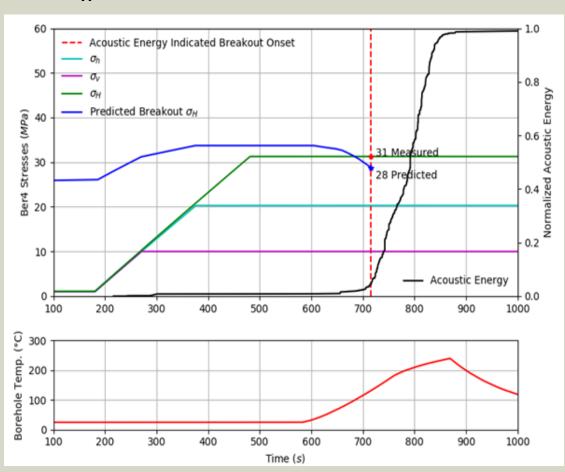




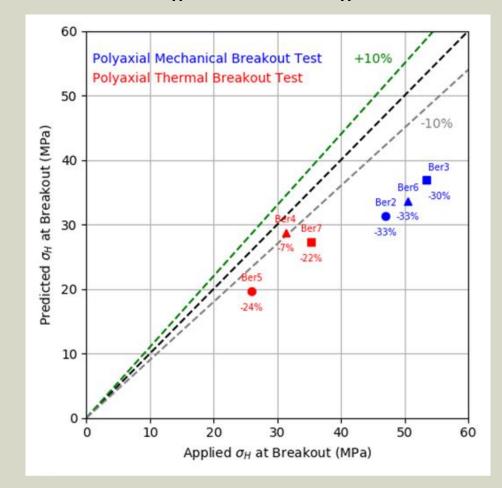




σ_H Prediction for Individual (*Ber4*) Test



Predicted σ_H vs. Applied σ_H (all tests)



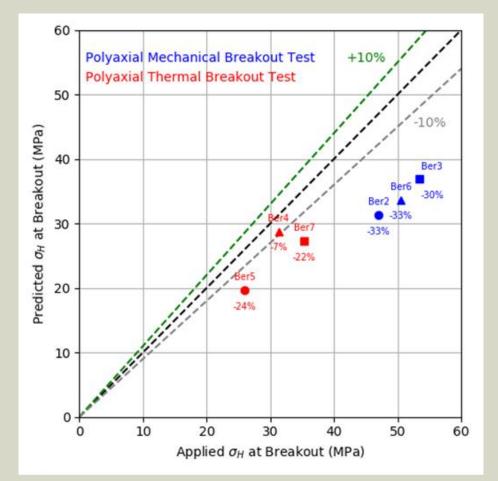


LAB TESTING — SUMMARY



- Lab testing is complete
- 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

Predicted σ_H vs. Applied σ_H (all tests)



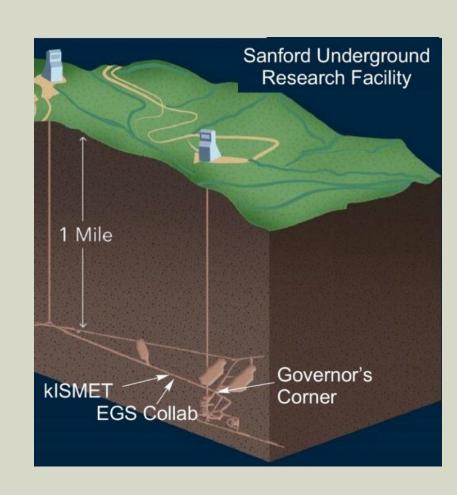
FIELD TESTING



FIELD TESTING - SURF



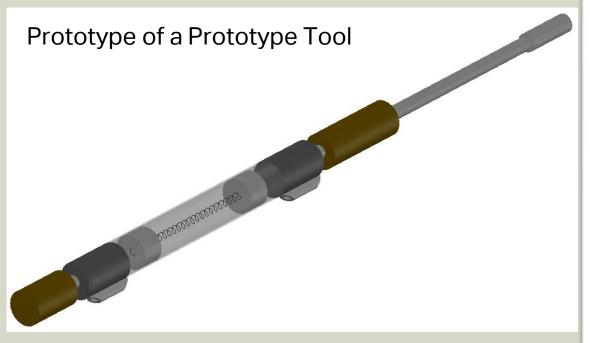
- Field testing is occurring at the Sanford Underground Research Facility (SURF) in South Dakota
 - / Abandoned gold mine that was converted to a deep underground science laboratory
 - / Several DOE-sponsored projects are being conducted at SURF
- Initial thermal breakout testing was performed on the 4850L in existing, free boreholes (2019-2020)
 - / Prototype of a prototype downhole tool
 - / Initial proof of concept
- We are moving to the 4100L for our next round of testing
 - / Drilling new boreholes just for us
 - / Will test full prototype tool

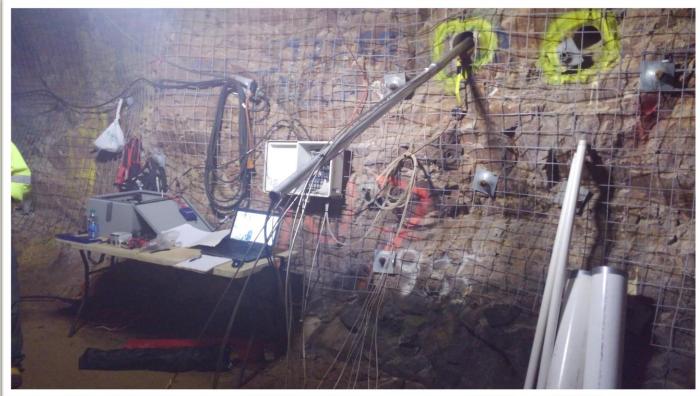




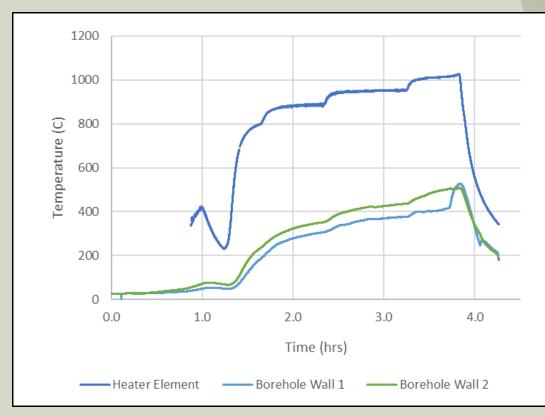
FIELD TESTING — 4850L

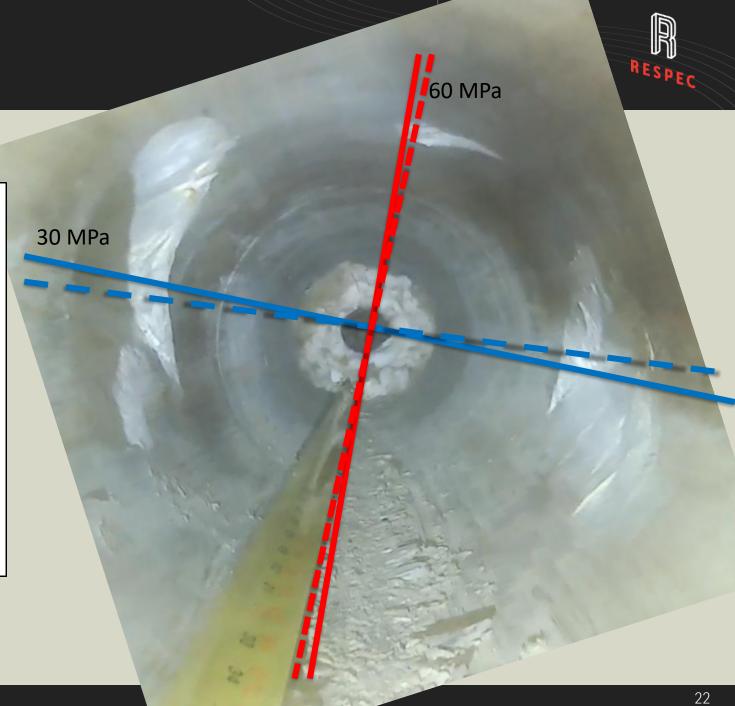






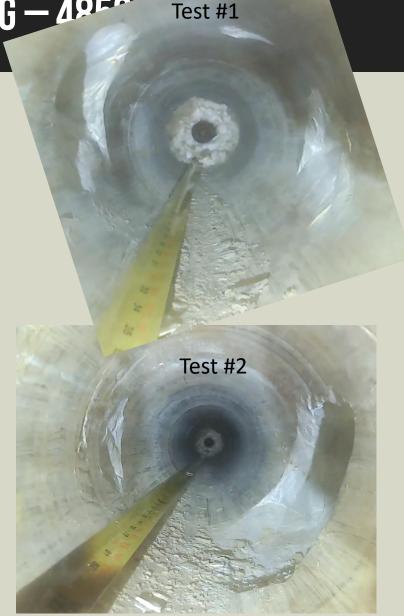
FIELD TESTING — 4850L





FIELD TESTING — 1950 Test #1







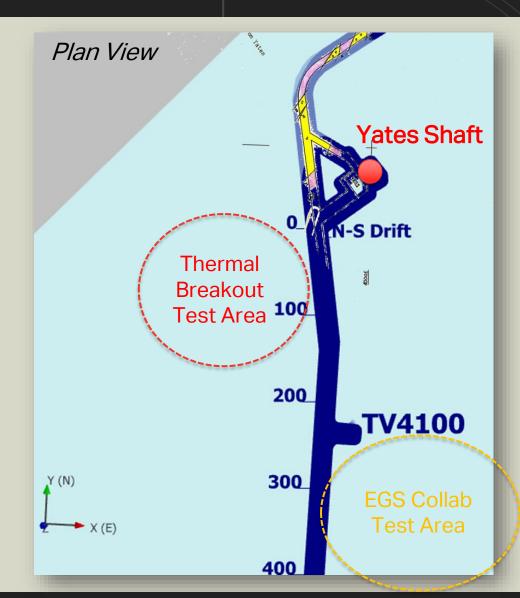


jay.nopola@respec.com

FIELD TESTING — 4100L



- We had previously been testing on the 4850L.
- Lost access to 4850L in 2020 because of a large DOE-OS-funded particle physics project (Fermilab)
- We are moving to the 4100L
- Our experiments will be next door to another DOE-EERE project that is investigating geothermal fracture stimulation (EGS-Collab)





FIELD TESTING — TH4100





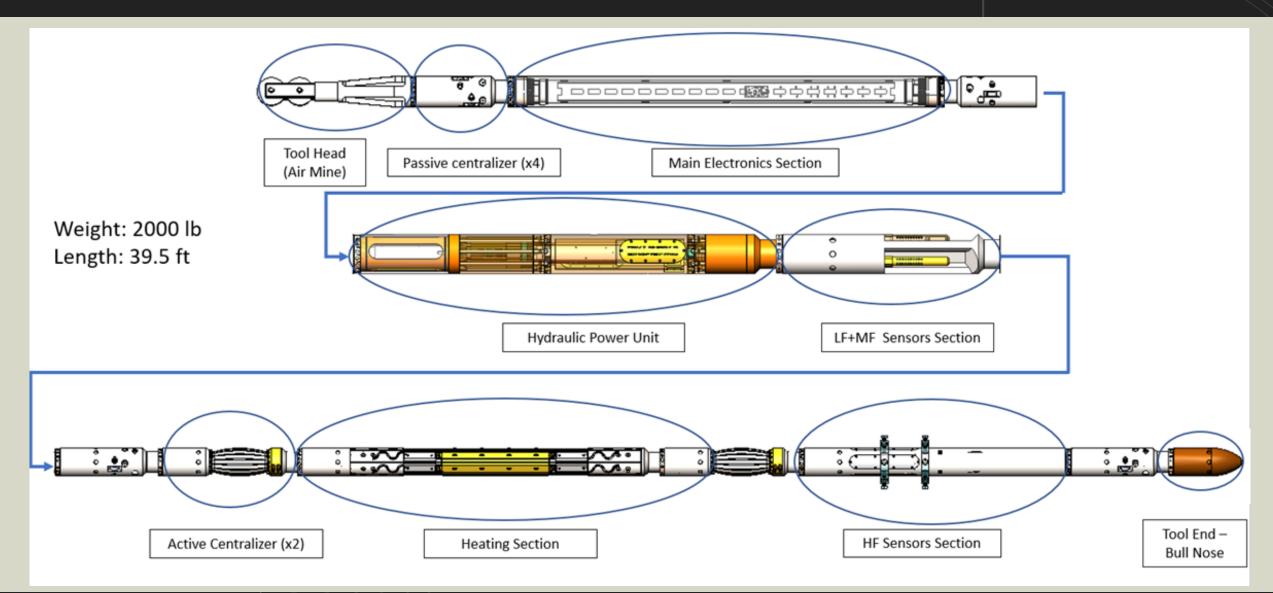


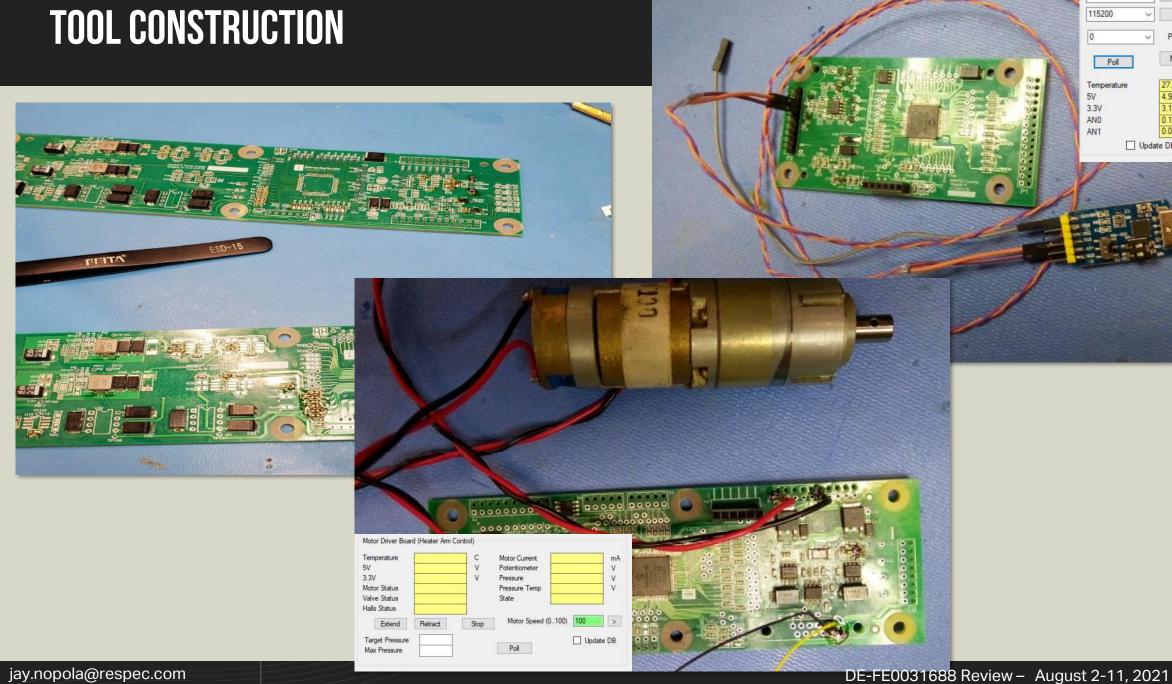
TOOL CONSTRUCTION



TOOL CONSTRUCTION

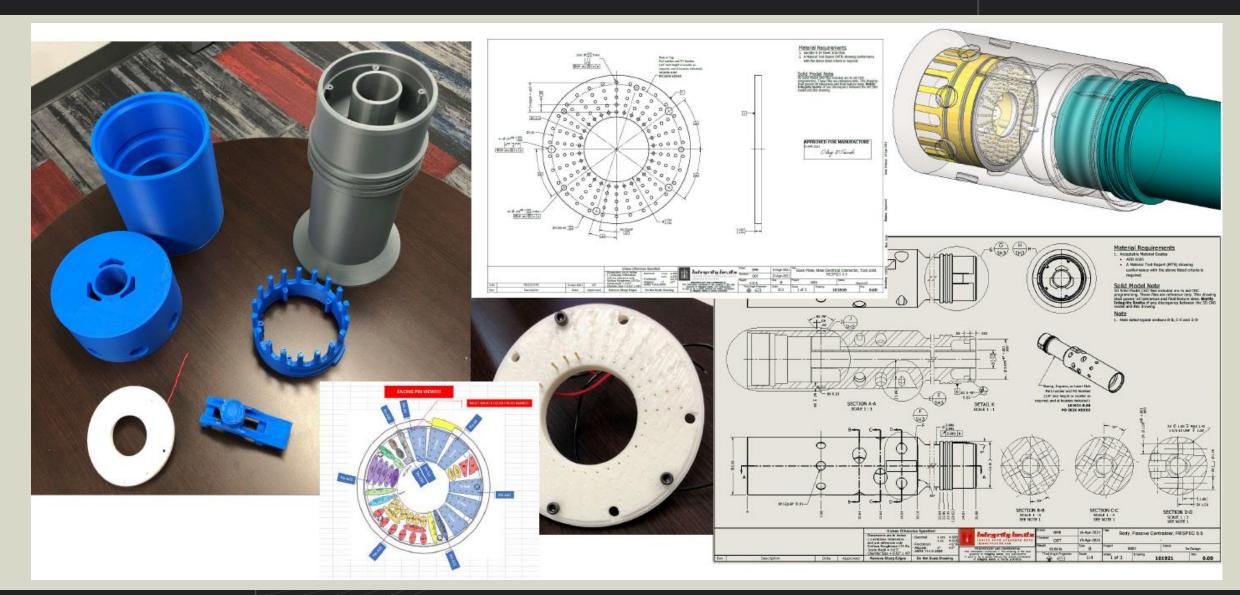


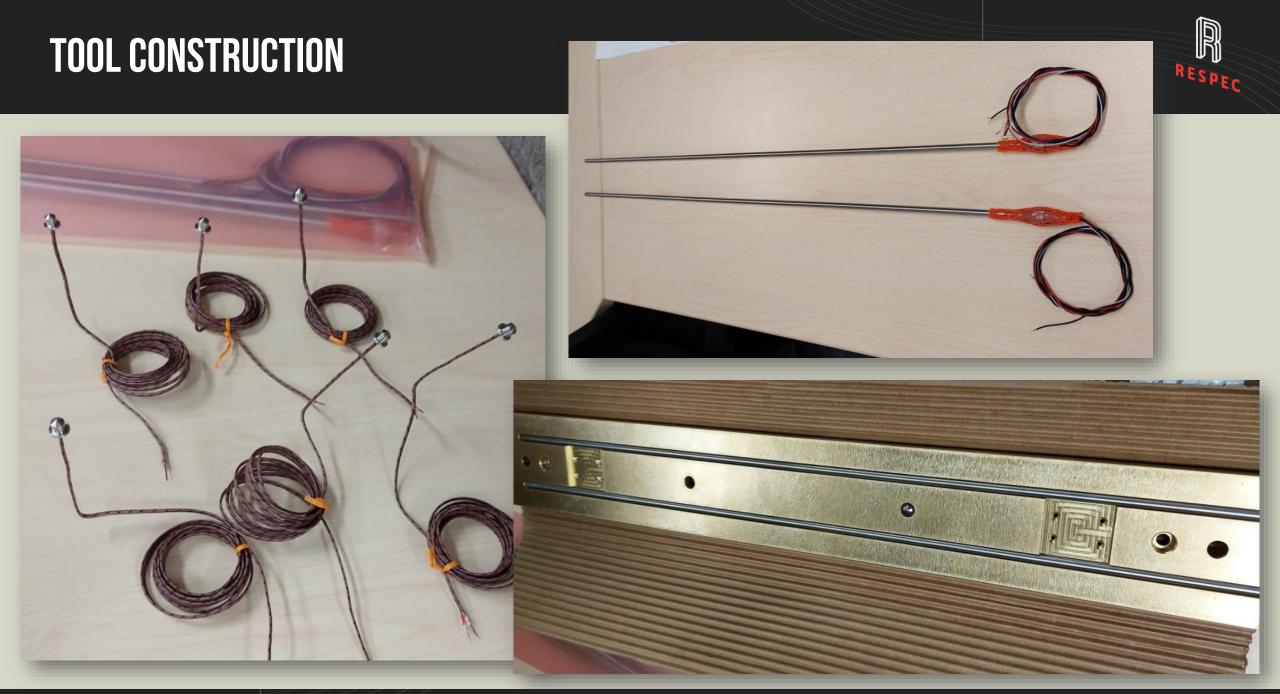




TOOL CONSTRUCTION







AGENDA

- INTRODUCTION
- TECHNICAL STATUS
- ACCOMPLISHMENTS TO DATE
- LESSONS LEARNED
- SYNERGY OPPORTUNITIES
- SUMMARY



ACCOMPLISHMENTS TO DATE



- Analytical and numerical thermomechanical modeling confirms theoretical concept
- Laboratory testing validates that thermally-induced breakouts can be created and correspond to the applied stress state
- Field testing demonstrates consistent thermal breakout creation in relation to in situ stress
- Tool design is feasible and construction is achievable
- Published (2) journal manuscripts and (3) conference papers



AGENDA

- INTRODUCTION
- TECHNICAL STATUS
- ACCOMPLISHMENTS TO DATE
- <u>LESSONS LEARNED</u>
- SYNERGY OPPORTUNITIES
- SUMMARY



LESSONS LEARNED



- Anticipate some partnering/contracting issues
- Benefits of preliminary but simple tests for initial proof of concept/learning
- Select rock types that are compatible with test frame limitations
- Rock strength and acoustic emission criteria are critical for quantitative analysis
- Difficulty measuring "true" borehole wall temperature
- Expect scheduling delays with coordinating field activities between DOE projects
- Plan for supply and material costing issues in response to variable post-pandemic market



AGENDA

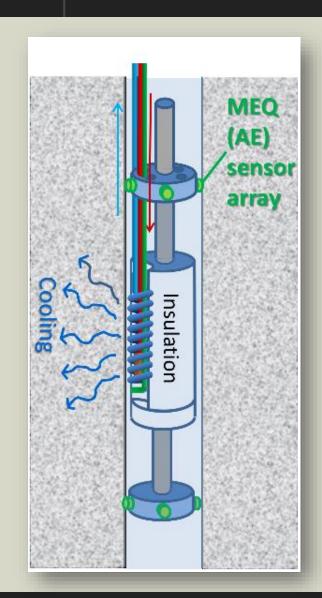
- INTRODUCTION
- TECHNICAL STATUS
- ACCOMPLISHMENTS TO DATE
- LESSONS LEARNED
- SYNERGY OPPORTUNITIES
- SUMMARY



SYNERGY OPPORTUNITIES



- Awarded SBIR project (DE-SC0020003) for thermally activating salt
- Awarded DOE Geothermal Technologies Office project (DE-EE0009033) for a related thermal cooling stress measurement concept
- Sharing field-testing data with neighboring DOE project (EGS Collab DE-AC02-05CH11231)
- Performed experimental thermal breakout tests in the mining sector



AGENDA

- INTRODUCTION
- TECHNICAL STATUS
- ACCOMPLISHMENTS TO DATE
- LESSONS LEARNED
- SYNERGY OPPORTUNITIES
- <u>SUMMARY</u>



SUMMARY

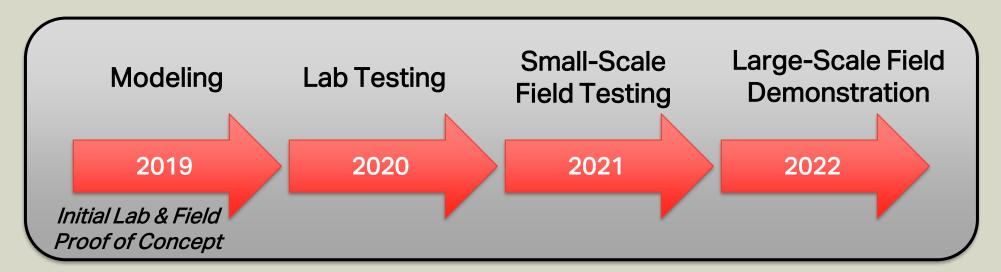


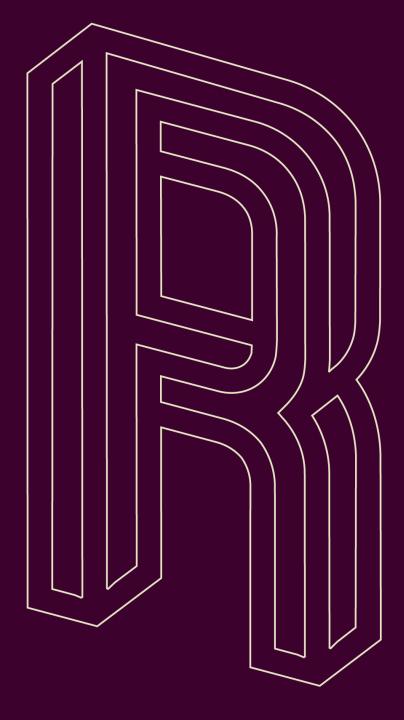
Key Findings:

- / Heat can consistently induce breakouts (in lab and field)
- / Breakout onset and orientation correspond to stress magnitude and direction
- / Rock strength and acoustic emission criteria are critical

Next Steps:

- / Drill new experimental boreholes in underground laboratory and test prototype thermal tool
- / Perform full-scale field test in actual O&G borehole





jay.nopola@respec.com





APPENDIX

DE-FE0031688 Review - August 2-11, 2021 - jay.nopola@respec.com



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 CO2 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 and construction
- SURF: Small-scale field testing facility
- Nange Resources: Large-scale borehole demonstration access



ORGANIZATION CHART



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

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

Plan Milestone Thermal Breakout Schedule Decision Point Actual Responsible Pertinent Team **Project Month** PLAN PLAN Task **ACTIVITY** START DURATION 1 2 3 4 5 6 7 8 9 10 11 12 | 13 14 15 16 17 18 19 20 21 22 23 24 Lead Resources Project Management/Planning, Administration, RESPEC 48 1 and Technical Advisory Committee **Engineering Design and Numerical Modeling Initial Numerical Modeling** RESPEC LBNL 6 **Initial Engineering Design Requirements** RESPEC BHGE, TAC **Modeling Evaluation of Subsurface Factors** RESPEC LBNL **Laboratory Testing** 3.1 **True-Triaxial Borehole Breakout Tests** 18 UW **Shaped Core Uniaxial Tests** LBNL UW 13 19 **Shaped Core Thermal-Poromechanics Tests** RESPEC LBNL **Confirmation Modeling** 16 RESPEC LBNL 9 **SURF Field Testing** 4.1 **Prototype Tool Design and Construction** RESPEC BHGE, TAC 19 12 4.2 **Safety and Access** 22 15 SURF **TEAM** 4.3 **Field-Scale Testing** 25 12 RESPEC TAC, UW, LBNL **Confirmation Modeling** 25 12 RESPEC LBNL **Deep Well Field Testing Prototype Tool Design and Construction** RESPEC BHGE, TAC 31 9 **Safety and Access** TBD TEAM 38 **Field-Scale Testing** BHGE, TAC 40 RESPEC **Confirmation Modeling** RESPEC LBNL 44 Year 1 Year 2



GANTT CHART — YEARS 3 AND 4

Thermal Breakout Schedule

Plan Milestone

Decision Point

Task	ACTIVITY	Responsible	Pertinent Team	PLAN	PLAN	Project Month																							
		Lead	Resources	START	DURATION	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48
	Project Management/Planning, Administration,	55555																											
1	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													
4.4	Confirmation Modeling	RESPEC	LBNL	25	12												A												
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																		4	Δ					
5.4	Confirmation Modeling	RESPEC	LBNL	44	6																							1	
										Υ	'ear	3										Ye	ear 4						



BIBLIOGRAPHY

- Nopola, J., S. Voegeli, J. Knight, T. Artz, and M. Jones, 2020. "Initial Field Testing in the Deep Subsurface for the Thermal Breakout Project for Measuring In Situ Stress," ARMA 20-1978, 54th US Rock Mechanics/Geomechanics Symposium, Golden, Co, June 23–26 (conference postponed because of COVID-19).
- Trzeciak, M., H. Sone, C.E. Bate, and H. Wang. 2020. Thermally-induced breakouts: insights from true-triaxial tests with acoustic emission monitoring. ARMA-20-1990. In Proceedings of the 54th US Rock Mechanics/Geomechanics Symposium, Golden, Co, June 23–26 (conference postponed because of COVID-19).
- Voegeli, S., J. Nopola, D.Moos, and T. Doe, 2020. "Deterministic and Statistical Modeling of a New Thermal Breakout Technology for Measuring the Maximum Horizontal In Situ Stress," SPE-201195-PA, SPE Journal, Richardson, TX.
- Trzeciak, M., H. Sone, S. Voegeli, C.E. Bate, and H. Wang. (2021). Laboratory evaluation of the thermal breakout method for maximum horizontal stress measurement. Rock Mechanics and Rock Engineering. Manuscript submitted for publication.