SAND2025-01527C

Field Deployment Updates on Geochemistry-based Wireline Tool to Characterize Fractures in Enhanced Geothermal Systems (EGS) Wells

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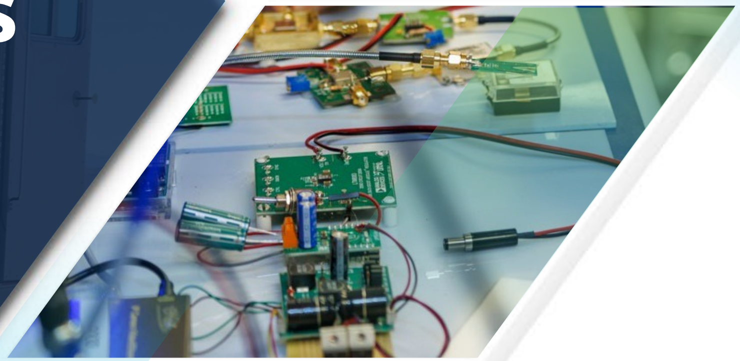

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Stanford Geothermal Workshop

February 10-12, 2025

U.S. DEPARTMENT OF ENERGY

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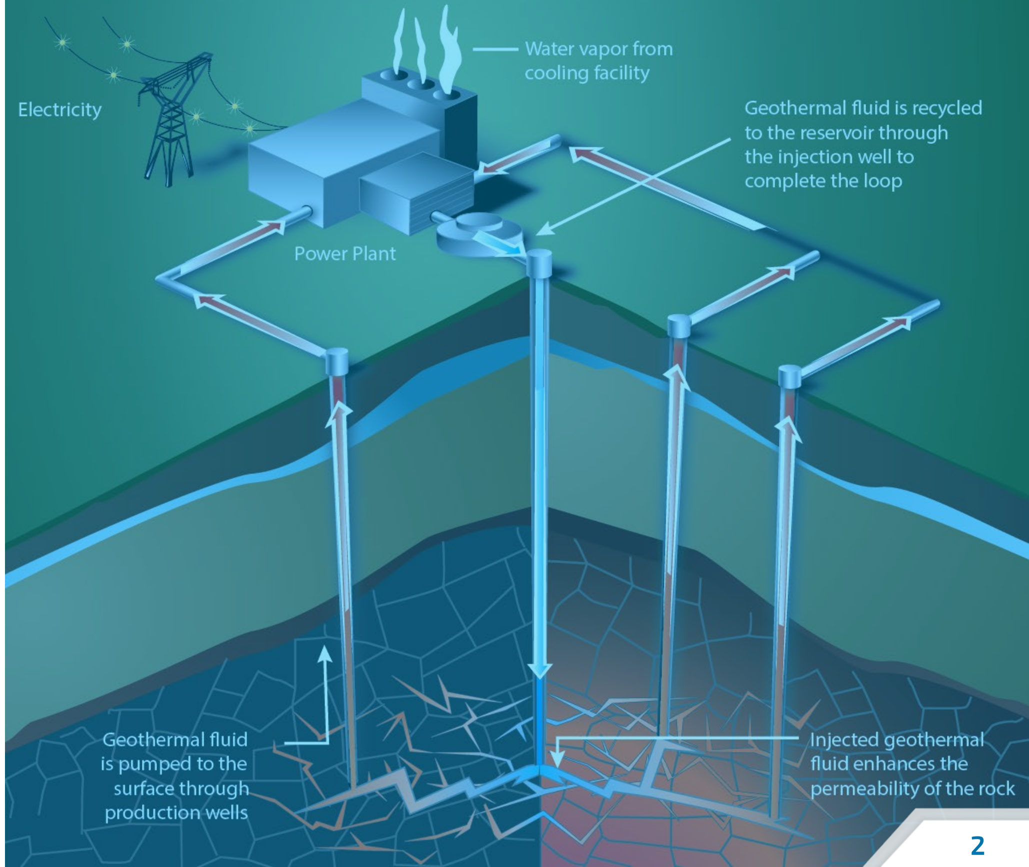
MOTIVATIONS & OBJECTIVES

- **Locate** and **quantify** the productivity of the artificial fractures in EGS wells to ensure **timely interventions** to keep fractures open and flowing.
- **Current solutions:**
  - Pressure-temperature-spinner (PTS) tool
    - Inconsistent in low fluid velocity, low enthalpy, and large diameter wells (Acuña and Arcedera, 2005).
  - 'Sewer cam' fracture flow imaging (shown at DoE's EGS Collab project at 4850 ft depth location)
    - Limited to shallow depths and low temperature
- **Goal of this research** is to develop a **high temperature, high pressure, geochemistry based tool** to map fractures and estimate their flow magnitudes

  → Validate at Utah FORGE

Source: Enhanced Geothermal System (EGS) Fact Sheet, Geothermal Technologies Office



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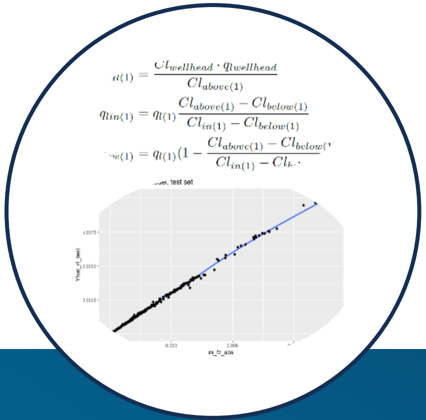
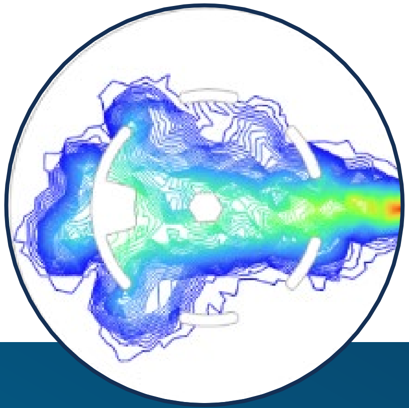
MULTIPRONGED APPROACH TO ITERATE TOOL DESIGN ACROSS CONFIGURATIONS

Understanding fluid flow behavior in EGS wells across configurations and inflow rate scenarios is necessary to optimize the chloride tool design, especially in the context of Utah FORGE field test.





ANALYTICAL & DATA-DRIVEN ANALYSIS

NUMERICAL SIMULATION

TOOL FABRICATION

LAB EXPERIMENTS

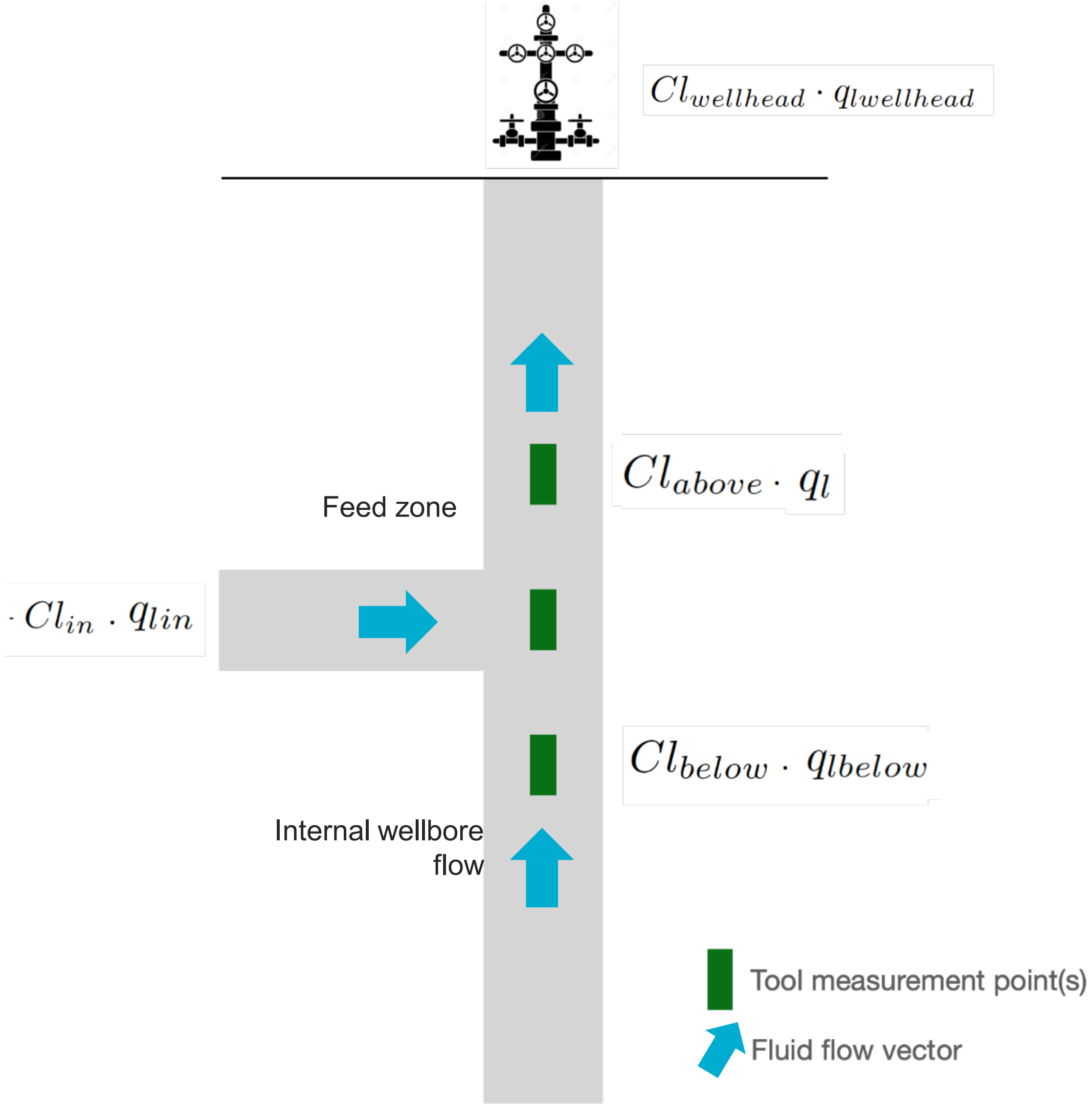
FIELD TESTING

GEOCHEMISTRY BASED APPROACH TO CALCULATE FLOW

- Sausan et al. (2022) developed an **analytical calculation** to quantify fracture flow rate based on chloride concentration measurements.

$$q_{in} = q_{above} \frac{Cl_{above} - Cl_{below}}{Cl_{in} - Cl_{below}}$$

- Chloride Ion selective electrodes used to selectively measure chloride ions in aqueous solution
  - Voltage generated proportional to chloride concentration in fluid



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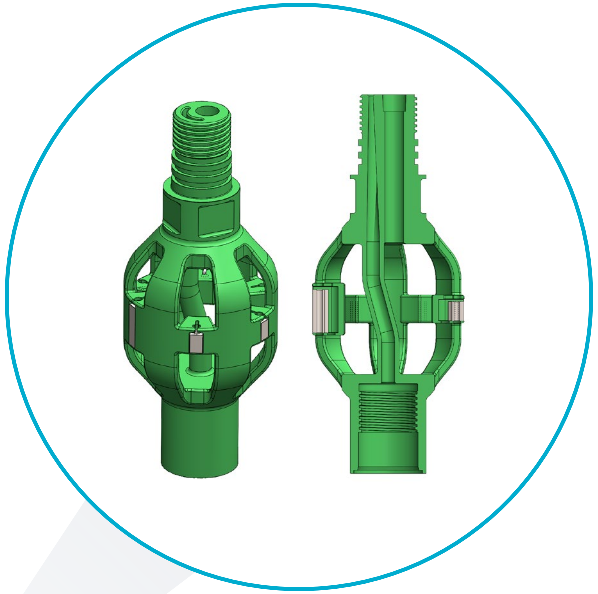
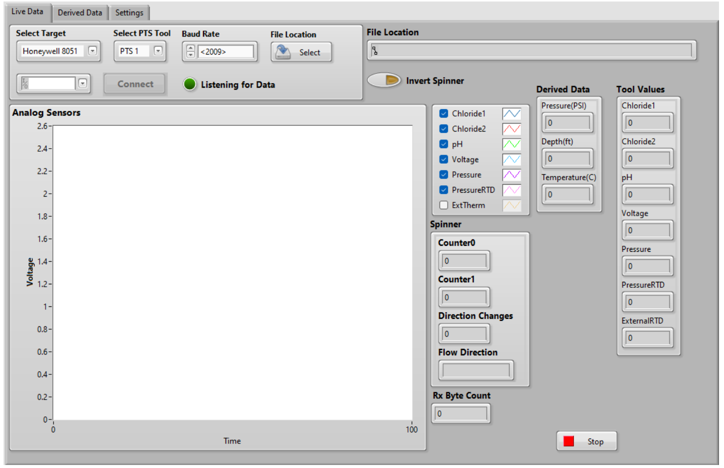
TOOL FABRICATION

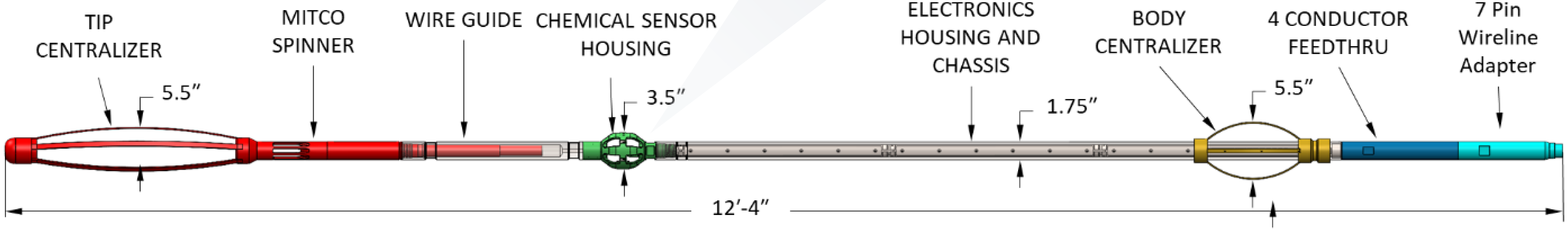
FIELD-SCALE CHLORIDE TOOL ASSEMBLY

The field-deployable chemical tool assembly incorporates the following:

- Mitco PTS sensor package for secondary measurements to compare to geochemistry based alternative
- Wire guide component to adapt PTS tool to chemical sensor tool
- Chemical sensor housing for Ion Selective Electrodes
- High-temperature logging tool in electronics housing
- LabView User Interface







FLOW EXPERIMENTS

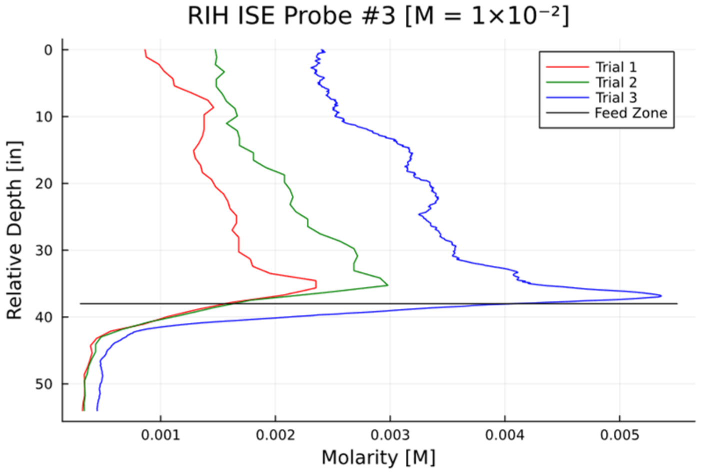
- Lab flow experiments conducted to understand behavior of chemical tool due to:
  1. Position relative to feed zone jet
  2. Presence of additional chemical species in feed zone fluid
- Observations:
  - Higher feed zone chloride concentrations produce the most accurate and repeatable responses for the ISE sensors
  - Significant interference due to presence of bromide and sulfate in feed zone fluid
    - ISE are imperfectly selective and particularly susceptible to these ions (Baker et al. 1980)

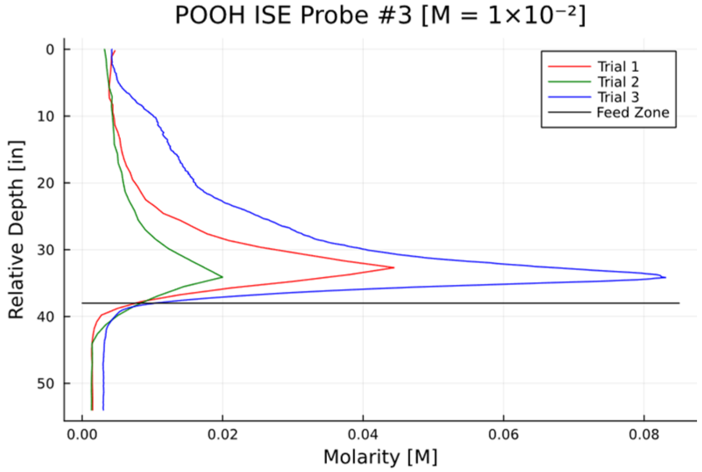
Lab-scale chemical tool in artificial well system. Red dye used to assist lab personnel visualize inflow.

TEST OF INTERPRETATION METHODS

- Validate analytical approach with Sandia chloride tool in the Stanford lab wellbore flow loop apparatus
- Chloride values measured above, below and at the feed zone depth
- Estimated inflow rate from chloride concentration showed good accuracy compared to the measured flow.

Feed Zone Chloride Concentration	Scenario	ISE Probe	Average Inferred Flow Rate (kg/s)	Percentage Error
1×10^{-1} mol/L	RIH	#2	1.256	993%
1×10^{-1} mol/L	POOH	#2	1.010	778%
1×10^{-1} mol/L	RIH	#3	0.730	535%
1×10^{-1} mol/L	POOH	#3	0.109	-5%
5×10^{-2} mol/L	RIH	#2	1.131	884%
5×10^{-2} mol/L	POOH	#2	0.877	662%
5×10^{-2} mol/L	RIH	#3	0.773	572%
5×10^{-2} mol/L	POOH	#3	0.031	-73%
1×10^{-2} mol/L	RIH	#2	0.866	653%
1×10^{-2} mol/L	POOH	#2	0.886	670%
1×10^{-2} mol/L	RIH	#3	0.393	242%
1×10^{-2} mol/L	POOH	#3	0.078	-33%





Molarity vs. Depth for ISE sensor in RIH and POOH directions for feed zone fluid with 1×10^{-2} mol/L

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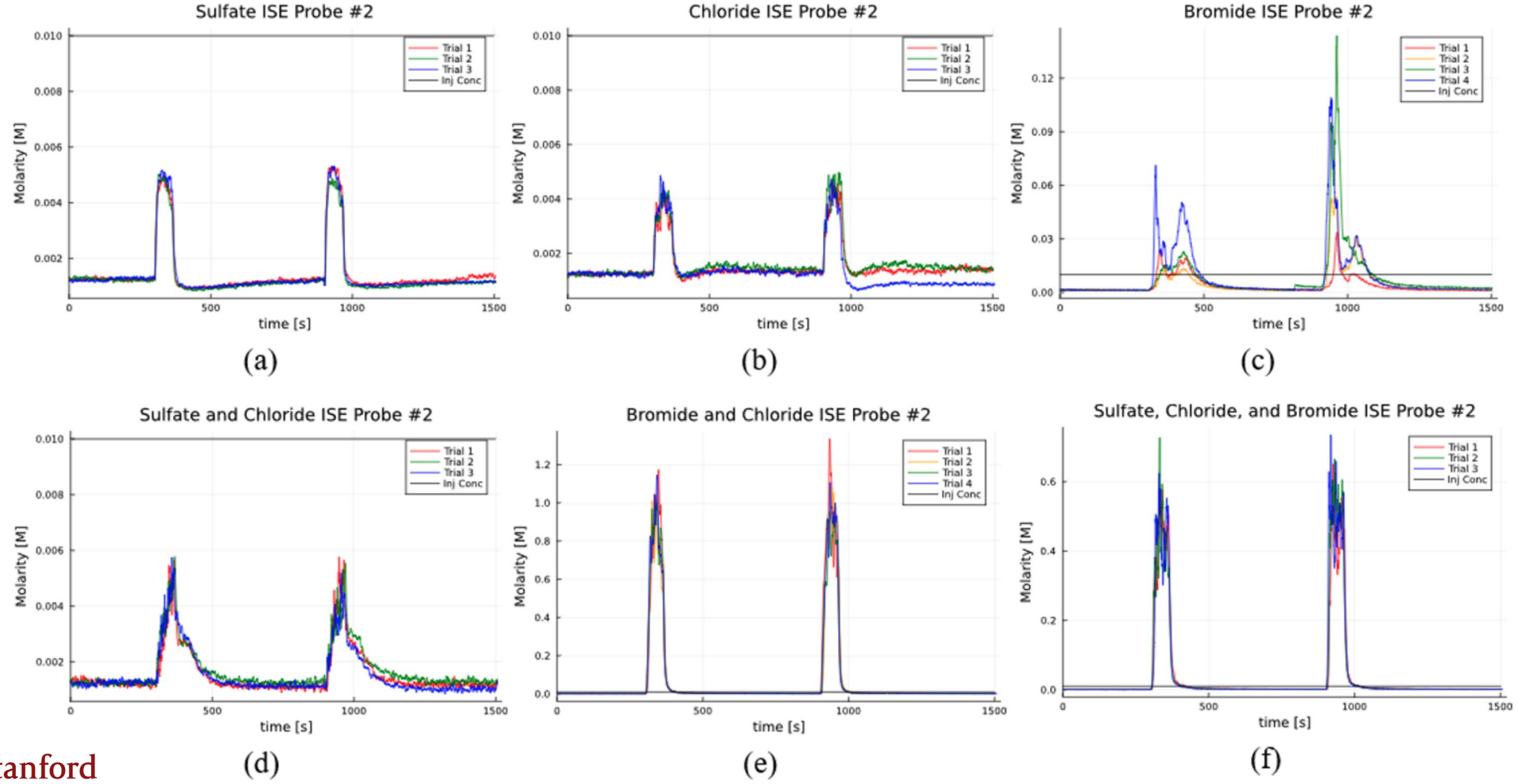
IMPACT OF CHEMICAL SPECIES ON CHLORIDE TOOL ACCURACY



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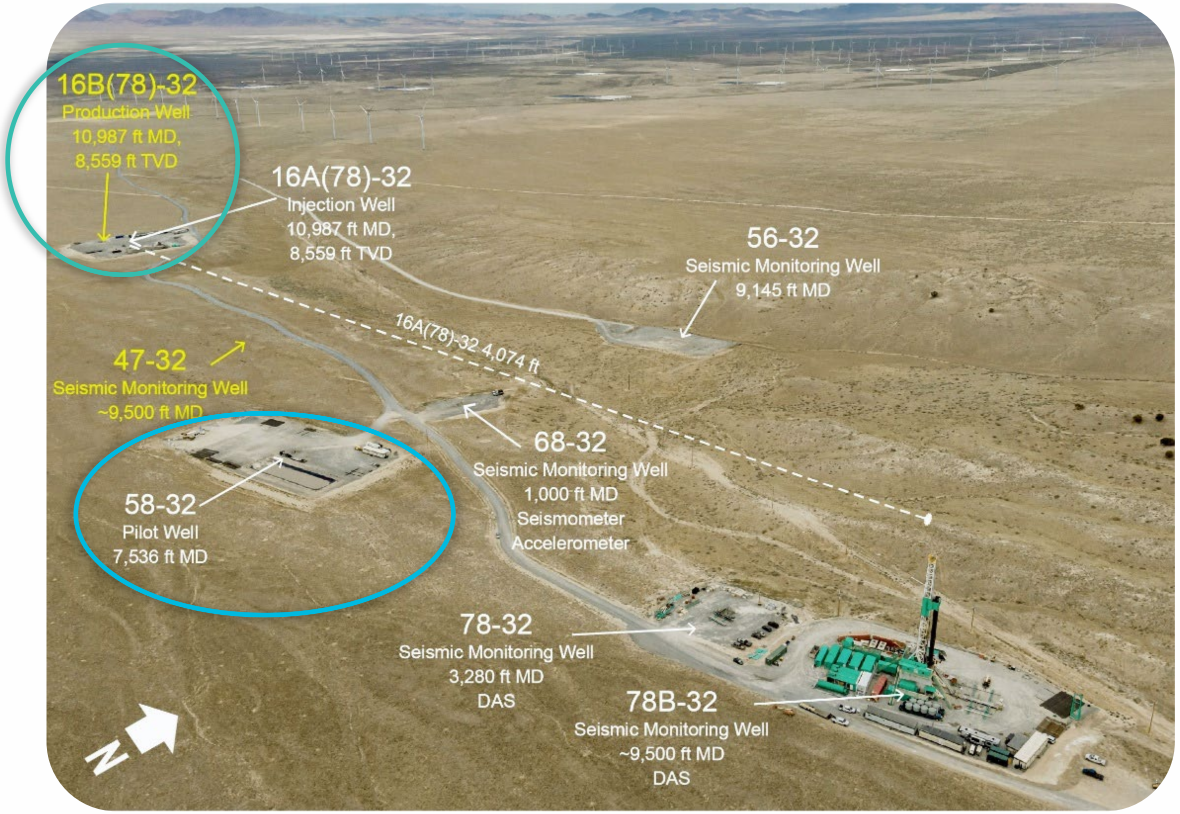
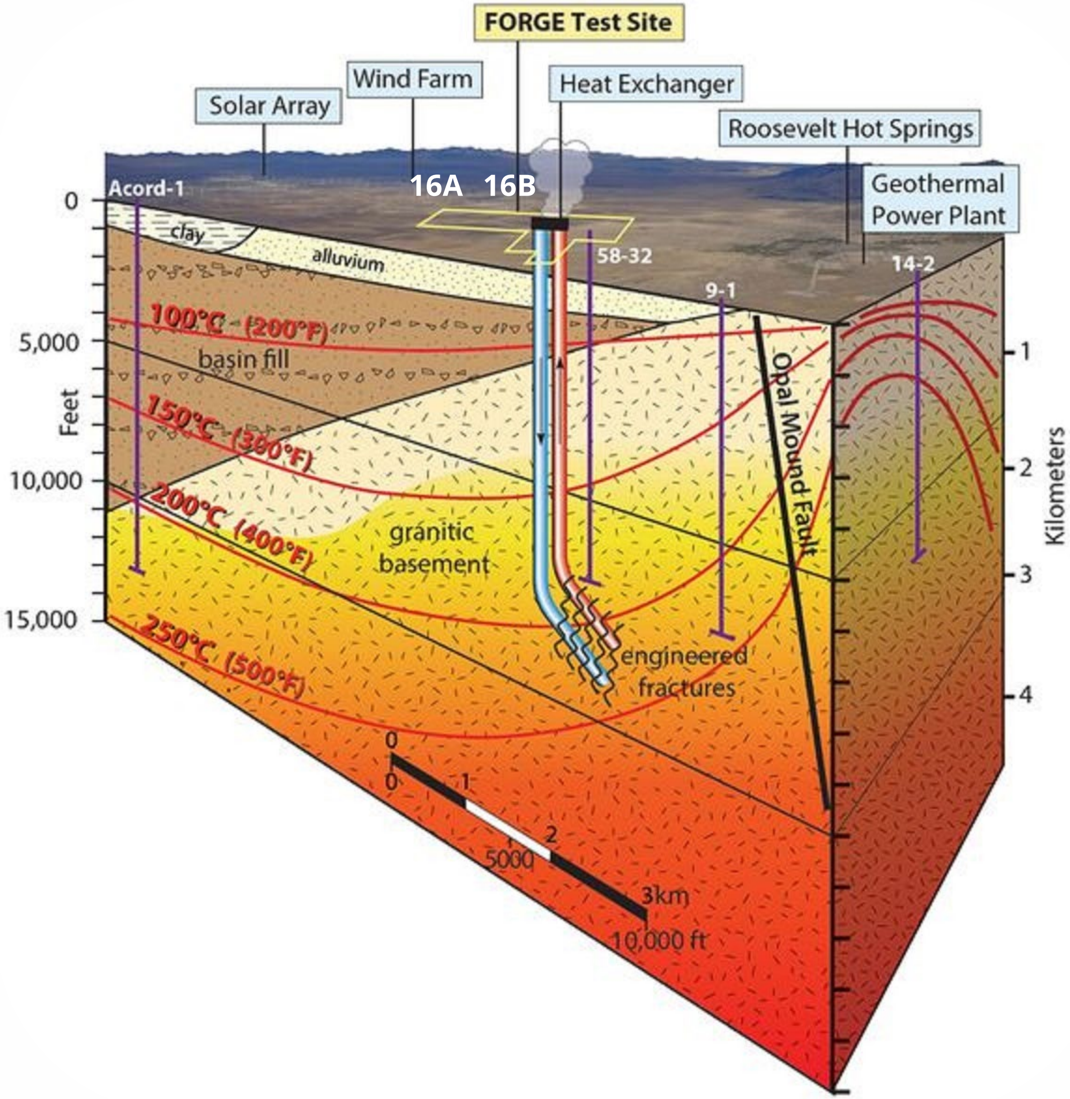
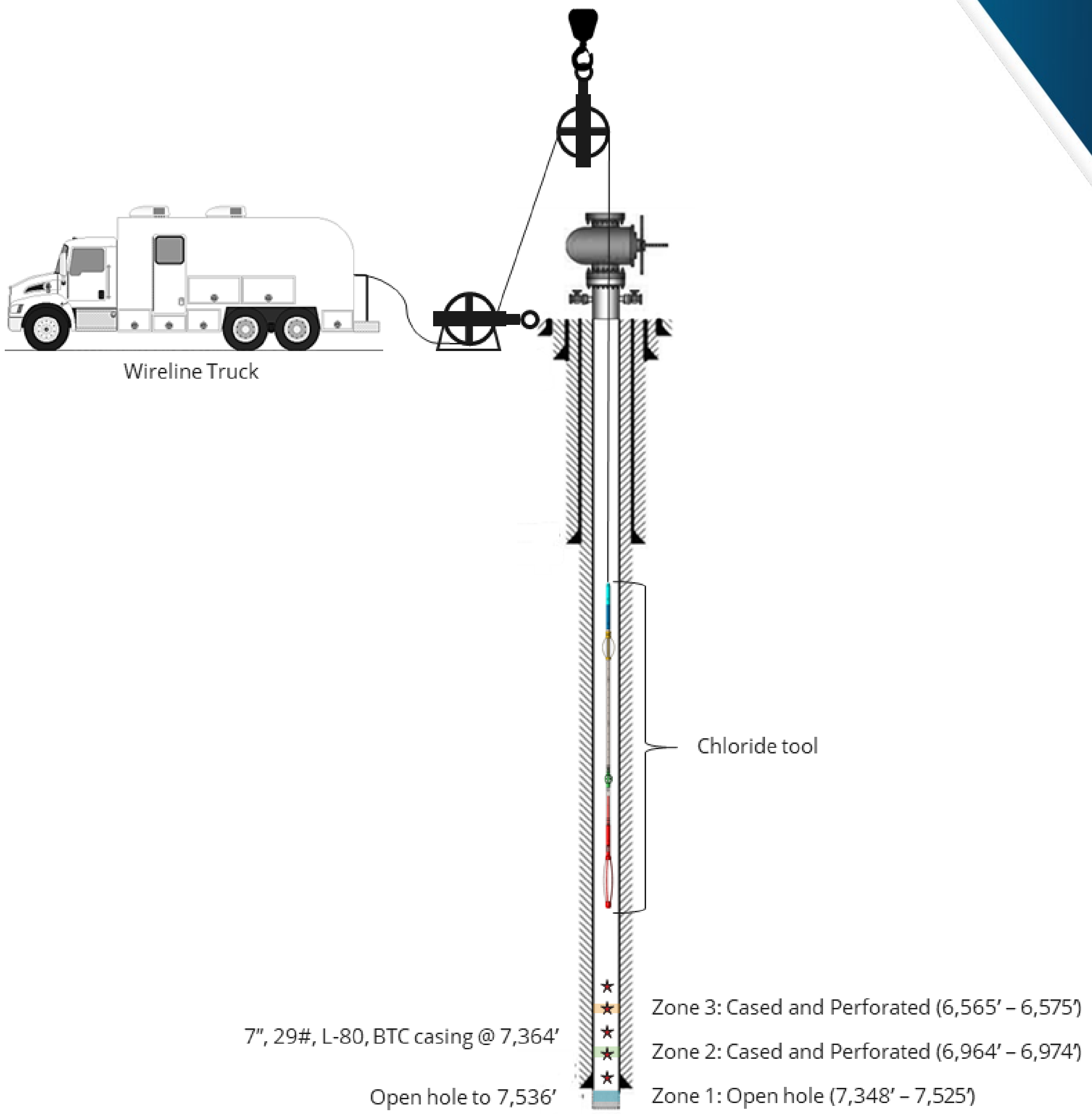
DEPLOYMENT AT WELL 58-32 AND 16(B)-32



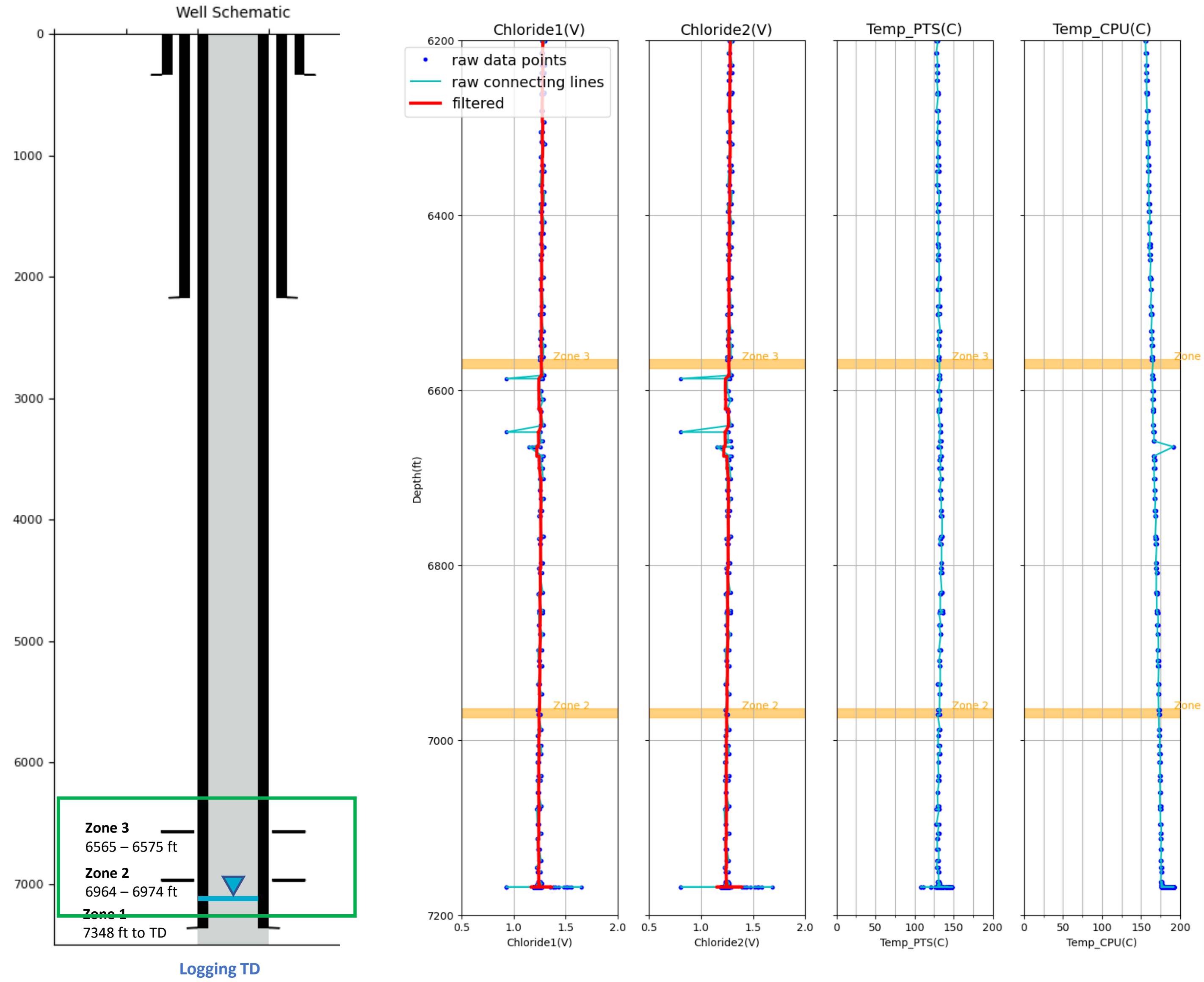


FIELD DEPLOYMENT UTAH FORGE WELL 58-32

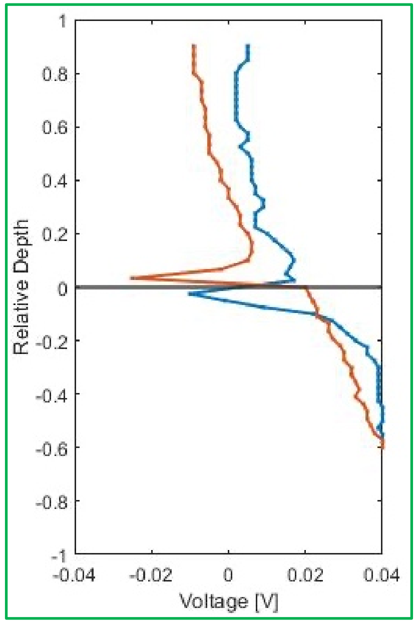
- Tool successfully deployed to 7,168 ft MD and recorded measurements at each test location during the run-in-hole (RIH) and pull-out-of-hole (POOH)
- Maximum measured temperature of 190˚C
- Measured data confirmed the successful operation of the tool
  - Noticeably better data quality during the POOH run compared to the RIH run
- Measurements suggest no internal flows in the well during the logging (well was not producing)



FLOW INDICATORS, RIH, FULL DEPTH, WELL 58-32 (NON-FLOWING)



Laboratory Dynamic Measurement Single Feed Zone



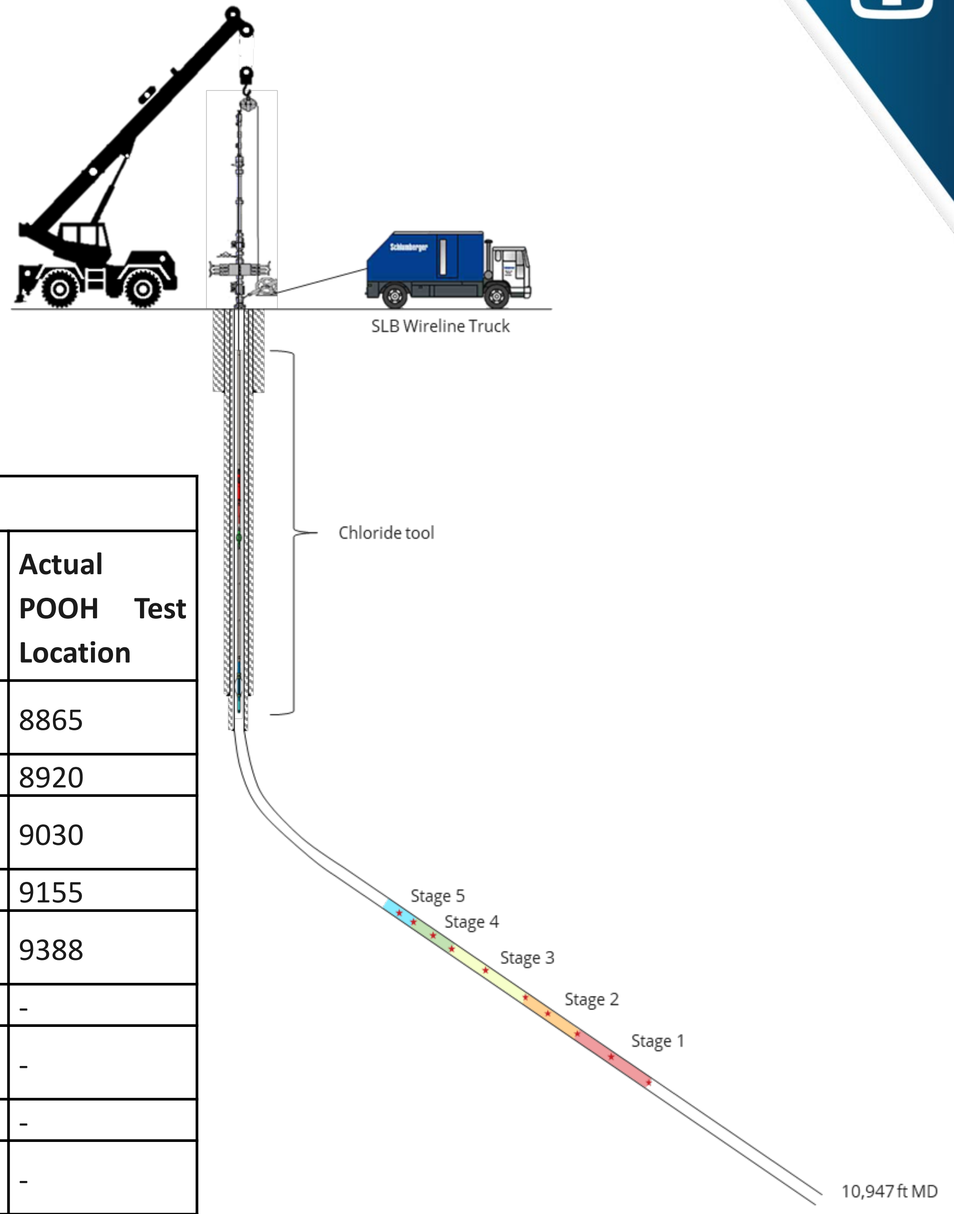
Zonal (6200 - 7200 ft) Logging results during Pull Out of Hole (POOH) at Utah FORGE Well 58-32

FIELD DEPLOYMENT UTAH FORGE WELL 16B

- Tool successfully deployed to approximately 9,480 ft
- Maximum measured temperature of 210˚C
- Measurement results indicate a change in chloride concentration in the perforation zones,

    → Suggests the chemical tool is capable of mapping fractures in a flowing well

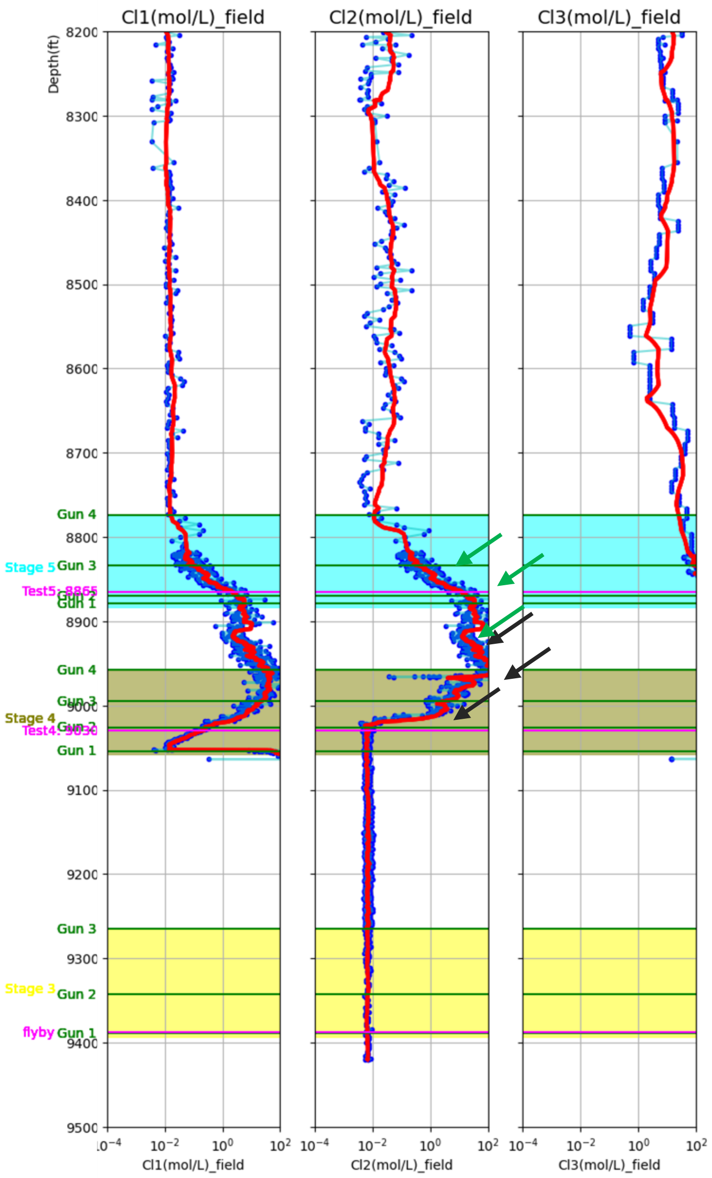
	Measured Depth (ft)							
	Gun 1	Gun 2	Gun 3	Gun 4	Gun 5	Planned Test Location	Actual RIH Test Location	Actual POOH Test Location
Stage 5	8500 - 8806	8806 - 8855	8855 - 8876	8876-8920		8865	8865	8865
						8920	8920	8920
Stage 4	8920 - 8978	8978 - 9013	9013 - 9042	9042 - 9155		9030	9030	9030
						9155	9155	9155
Stage 3	9155 - 9306	9306 - 9368	9368 - 9407			9388	9388	9388
						9407	-	-
Stage 2	9407 - 9440	9440 - 9455	9455 - 9469	9469 - 9495	9495 -9600	9462	-	-
						9600	-	-
Stage 1	9600 - 9720	9720 - 9753	9753 - 9765	9765 - 9800		9759	-	-
						9800	-	-



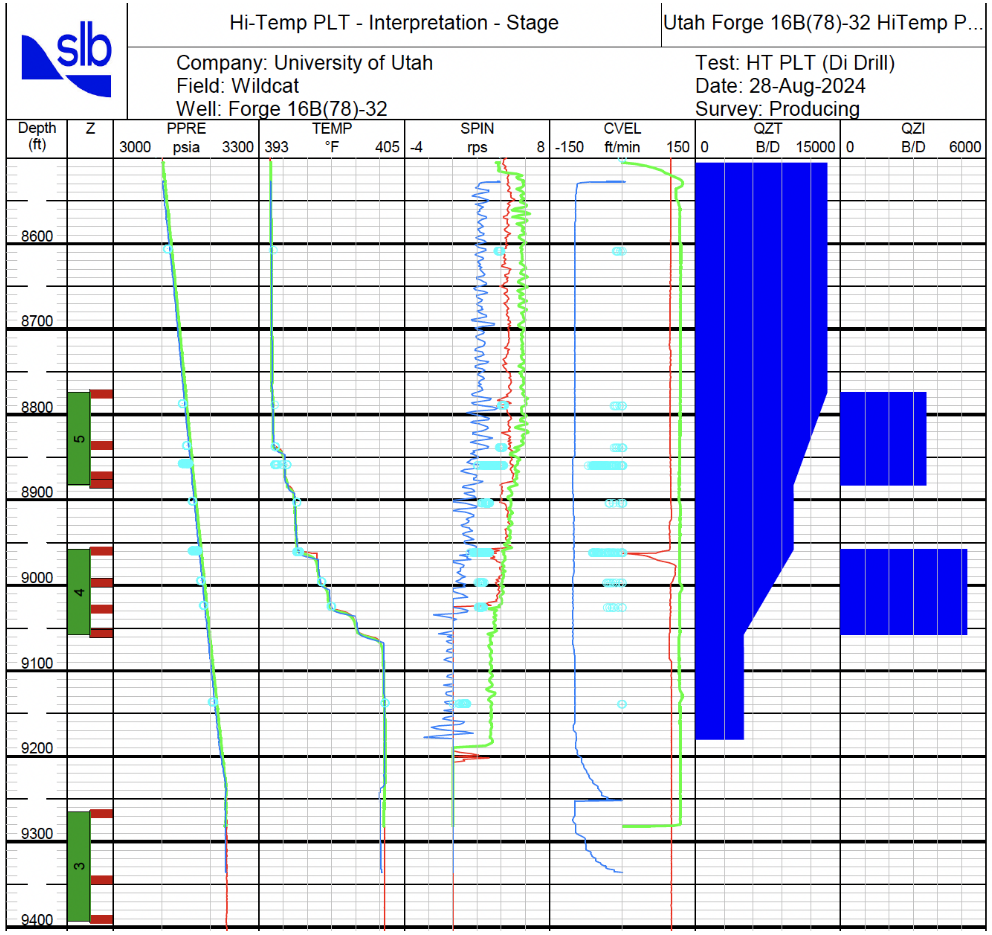
FLOW RATE CALCULATION, WELL 16B(78)-32 (FLOWING)

Stage 5: 4326.49 BPD

Stage 4: 7822.83 BPD



Depths aligned



Stage 5: 3122.2 BPD

Stage 4: 4573.9 BPD

SUMMARY

- Laboratory experiments tested various parameters affecting single fracture inflows and observed different probe behaviors.
- Bromide and sulfate ions caused interference but stabilized chloride readings; dynamic tests improved measurement accuracy.
- The tool was successfully deployed at FORGE Wells 58-32 and 16B(78)-32 in June and August 2024, respectively.
- Measurements obtained during the pull-out-of-hole (POOH) run were significantly more accurate than those during the run-in-hole (RIH) run.
- Flow rates calculated using the chloride method for well 16B(78)-32 were consistent with subsequent PLT log calculations, confirming accuracy.
- Lab and Field measurements indicate feasibility of chemical approach to map fractures in a geothermal well

ACKNOWLEDGEMENTS

This work is part of the Utah FORGE project under award number 3-2418 as a collaborative project between Stanford University and Sandia National Laboratory, supported by the U.S. Department of Energy.

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Design, development, and preparation of the field deployable tool and wireline truck: Jiann Su, Andrew Wright, Alfred Cochrane, Joe Pope, Joshua Tafoya, Taylor Myers, Manny Montano, and Joe Henfling

Special thanks to the field deployment team, Alfred Cochrane, Taylor Myers, Joseph Pope, Schlumberger and the Utah FORGE team without whom the field deployment would not have been a success.

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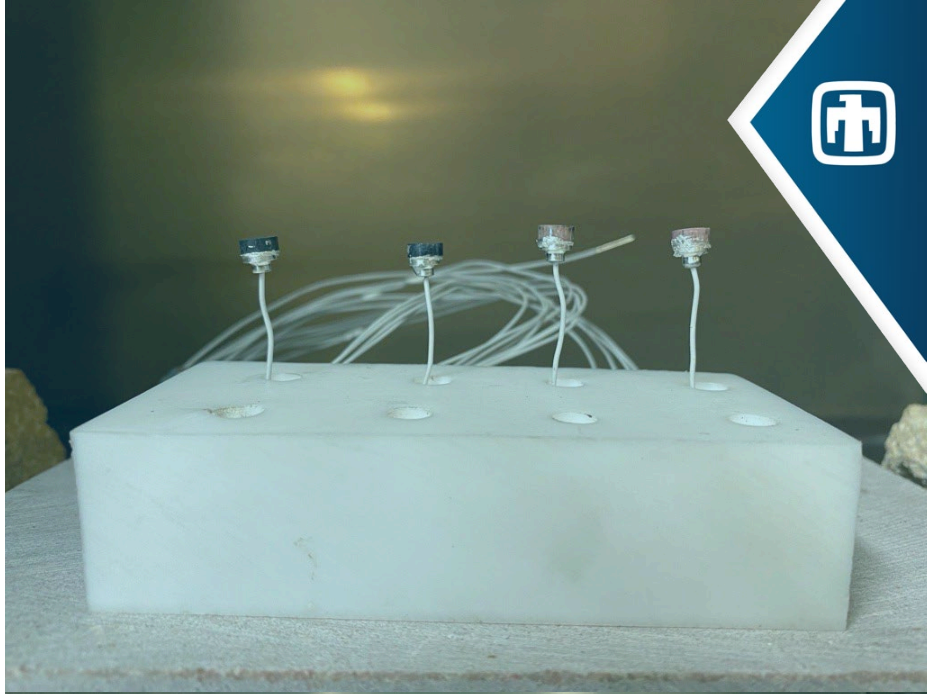
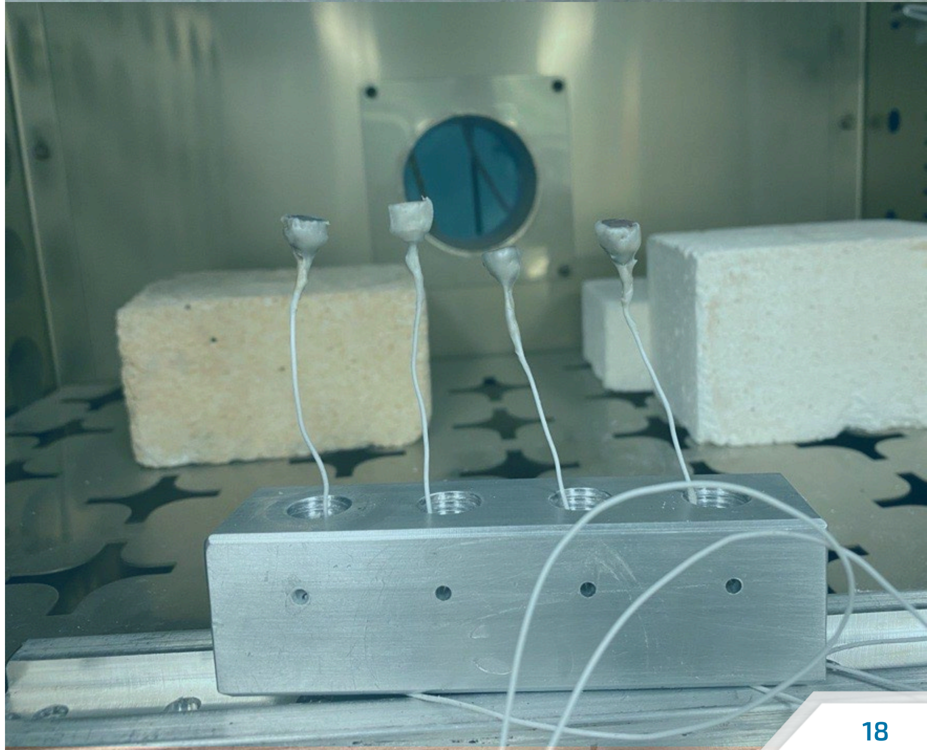
Questions?

CHLORIDE SENSOR FABRICATION AND TESTING

- Chloride ISE (AgS/AgCl Pellet)
  - Selectively transports chloride ions
  - Generates voltage proportional to chloride concentration in fluid
- Reference electrode (AgCl Pellet):
  - Reference potential for pair
- Manufacturing Process:
  - Powdered feedstocks are pressed in die presses to 4000 lbs.
  - Bonded to a CuAg wire adapter with conductive epoxy
  - Sensors covered with synthetic resin protective coating (gagekote)



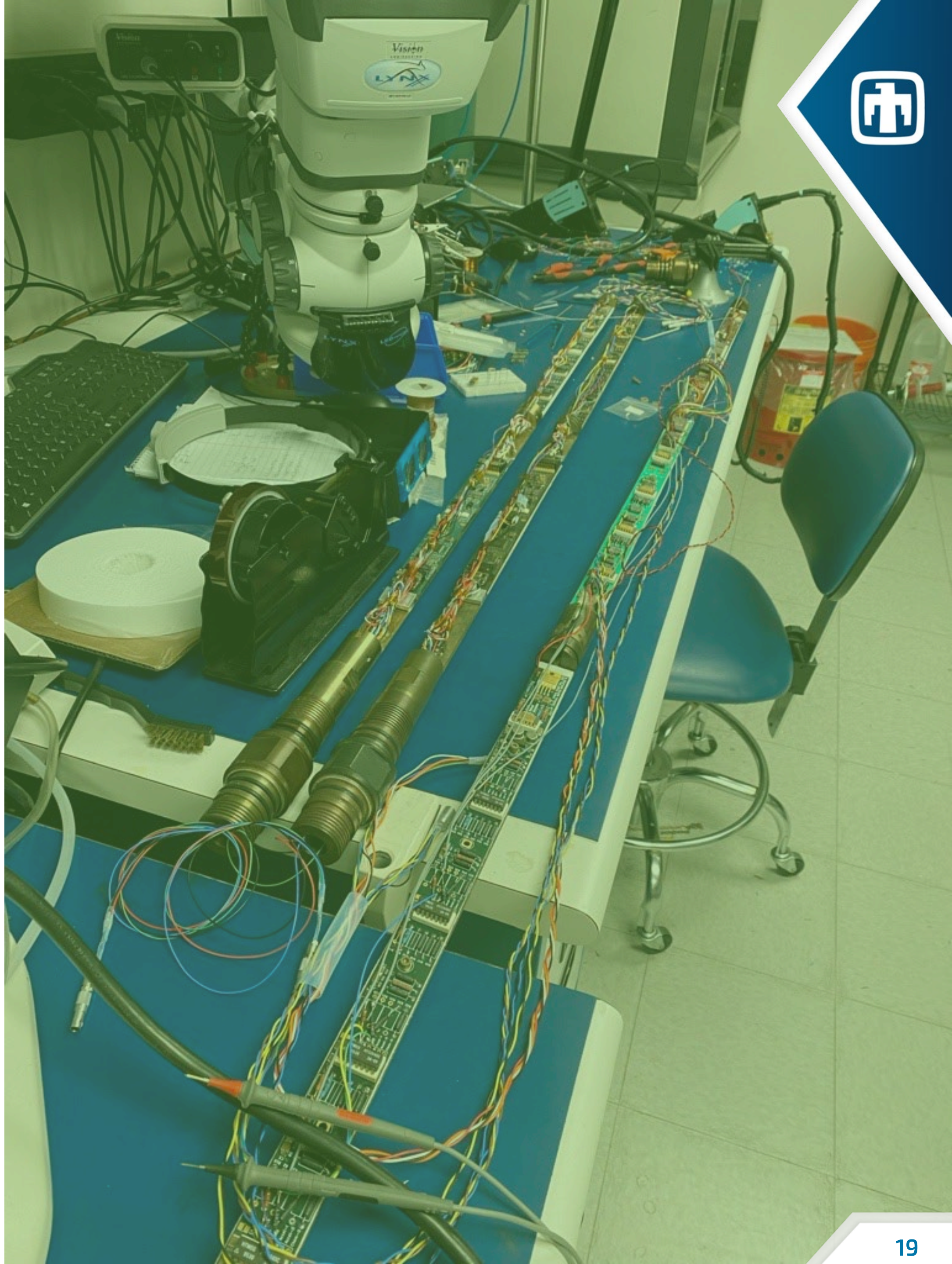


HIGH TEMPERATURE LOGGING TOOL

High-Temperature (HT) Logging Tool developed to transmit data to the surface.

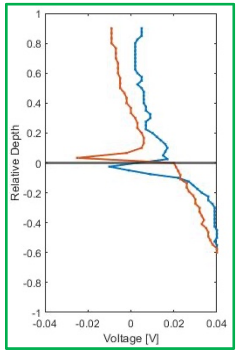
- EV-HT-200CDAQ1 High-Temperature Data Acquisition Reference Design Platform from Analog Devices
- Chemical Buffer Amplifier (CBA) which converts the chemical sensor high input impedance to low impedance

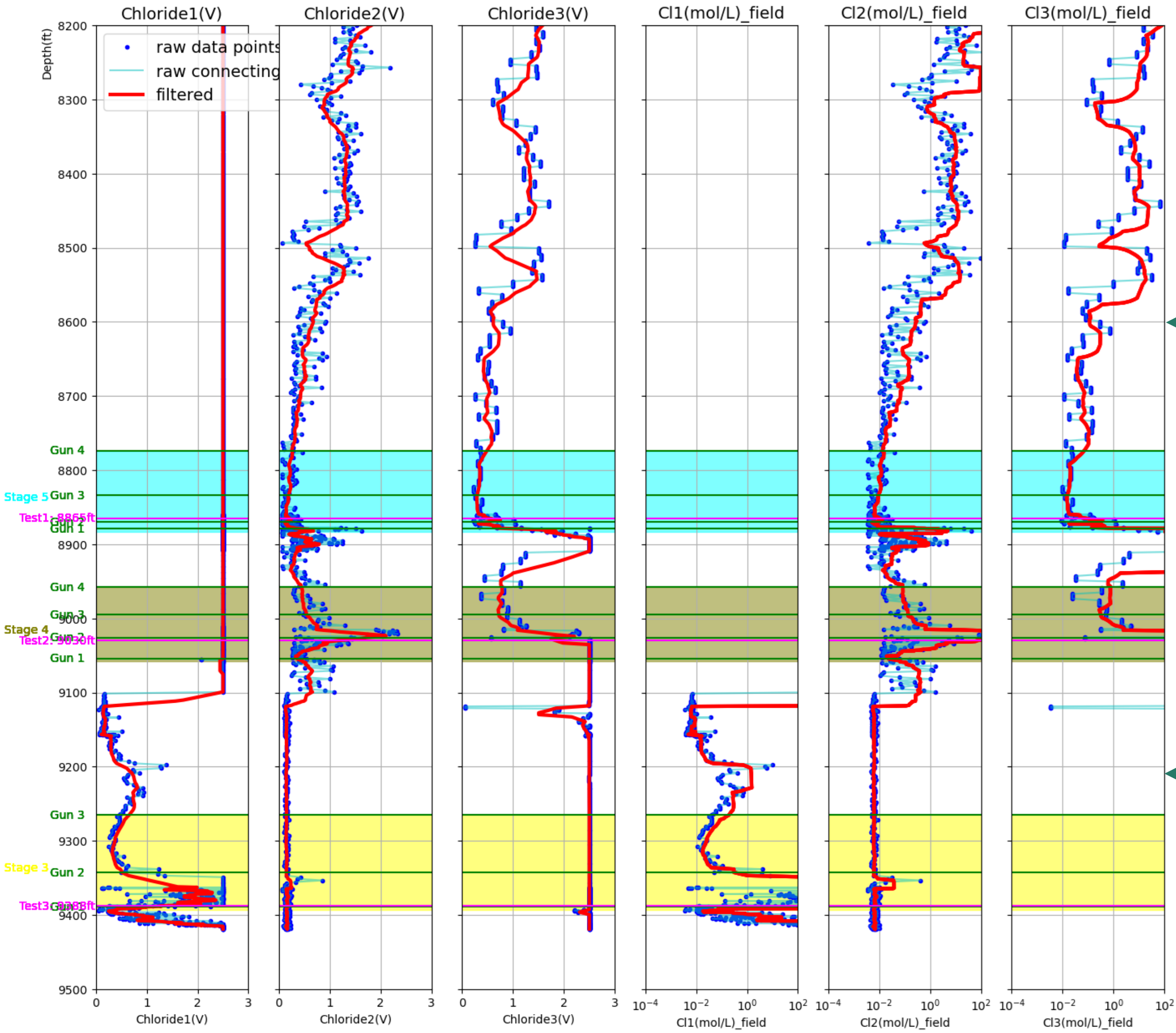
Rated for 200°C, tested to 210°C

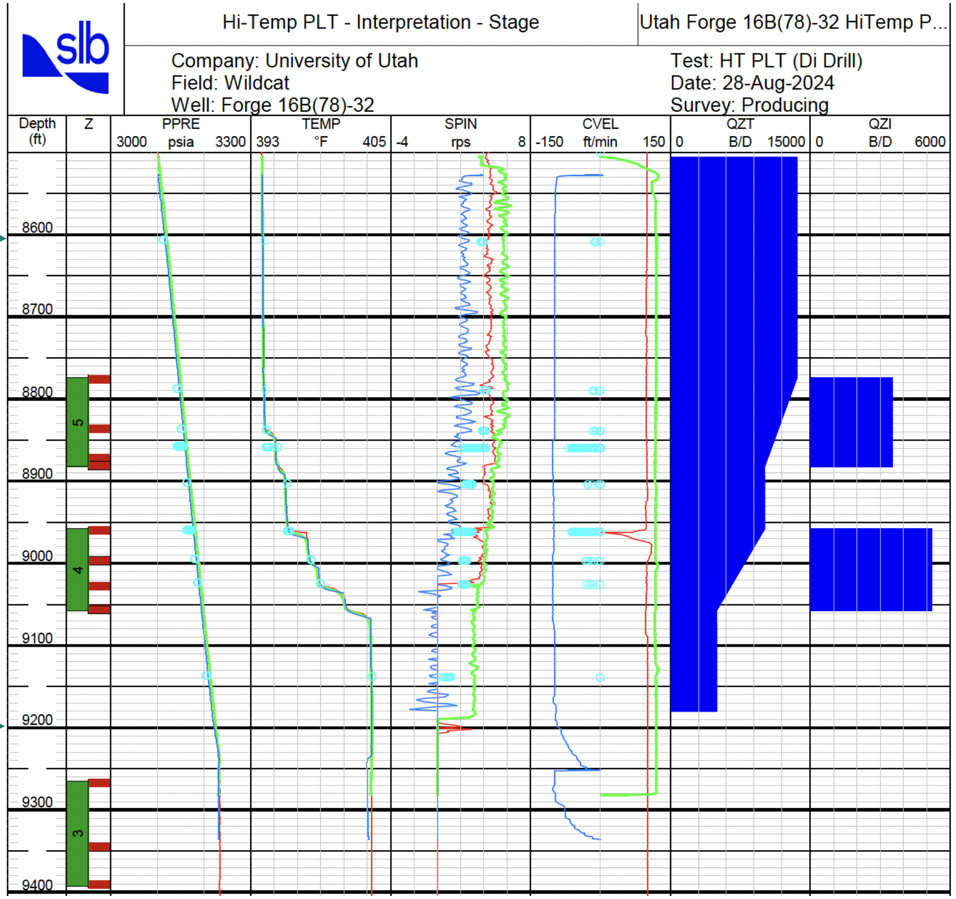


LOGGING RESULTS DURING RUN IN HOLE (RIH) AT UTAH FORGE WELL 16B

Laboratory Dynamic Measurement Single Feed Zone







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