

Salt: Introduction, Brine Availability Test in Salt (BATS), and Extended Plan

SFWST Meeting, Disposal Research
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MS-Teams

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Salt R&D Multi-Lab Team

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*Retired March 2021

Salt Host Rock Characteristics

Alpine miner at WIPP

Salt Long-term Benefits at km-scale

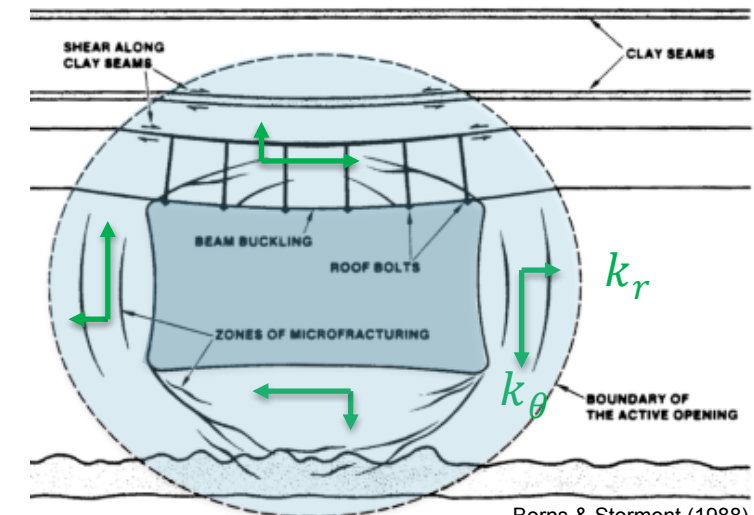
- Salt**
 - Low porosity ($\phi \leq 0.1$ vol-%) and permeability ($k \leq 10^{-22}$ m²)
 - High thermal conductivity (≥ 5 W/m · K)
 - High peak temperature ($T_{\max} \approx 200$ °C)
 - Openings creep closed ($> 10^0 - 10^2$ yr)
 - Run-of-mine salt heals to intact salt
- Brine**
 - No flowing groundwater (≤ 5 wt-% water)
 - Chlorine (≥ 190 g/L) → reduces criticality concerns
 - Hypersaline → reduces colloid mobility
 - Low water activity (< 0.75) → biologically simple

Near-field, Short-term Complexities

- EDZ**
 - ϕ and k higher near drift
 - Damage is highly anisotropic ($k_r < k_\theta$)



Cross-section view of Excavation Damaged Zone (EDZ) around drifts



Borns & Stormont (1988)

Salt Host Rock Characteristics - Brine

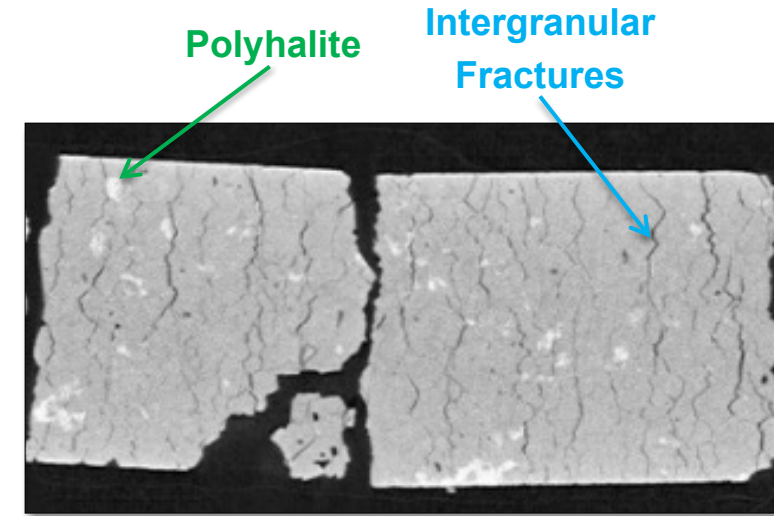
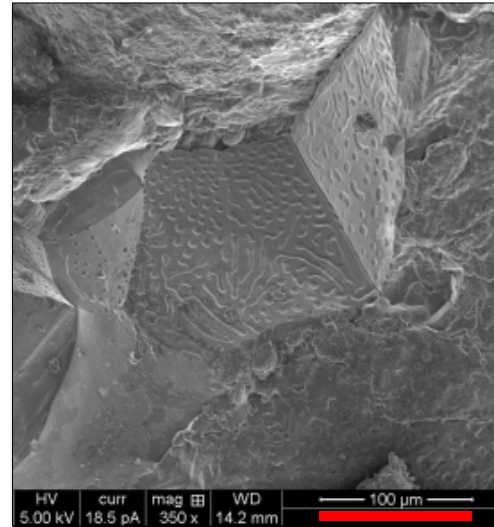
- Water in Bedded Salt from Permian Deposition*
 1. Disseminated clay (< 5 vol-%; ~25 vol-% brine)
 2. Intragranular fluid inclusions (1 – 2 vol-%)
 3. Hydrus minerals (e.g., $\text{K}_2\text{Ca}_2\text{Mg}(\text{SO}_4)_4 \cdot 2\text{H}_2\text{O}$; < 5 vol-%)
 4. Intergranular brine (<< 1 vol-%)



WIPP Fluid inclusions
2 mm scale bar
(Caporuscio et al., 2013)

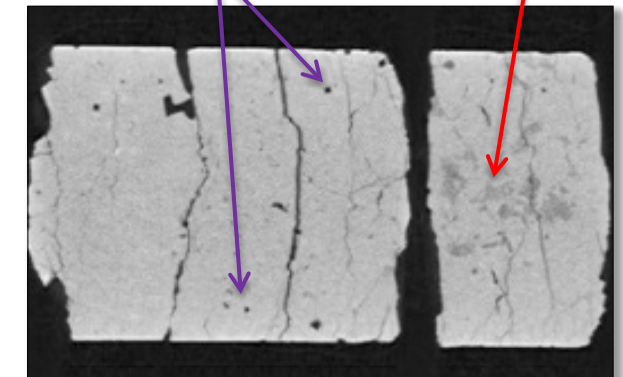


Intergranular fluid inclusions
in reconsolidated granular salt
100 μm scale bar
(Mills et al. 2018)



Intragranular Fluid Inclusions

Clay



10.1 cm diameter core X-ray CT data from BATS (Betters et al., 2020)

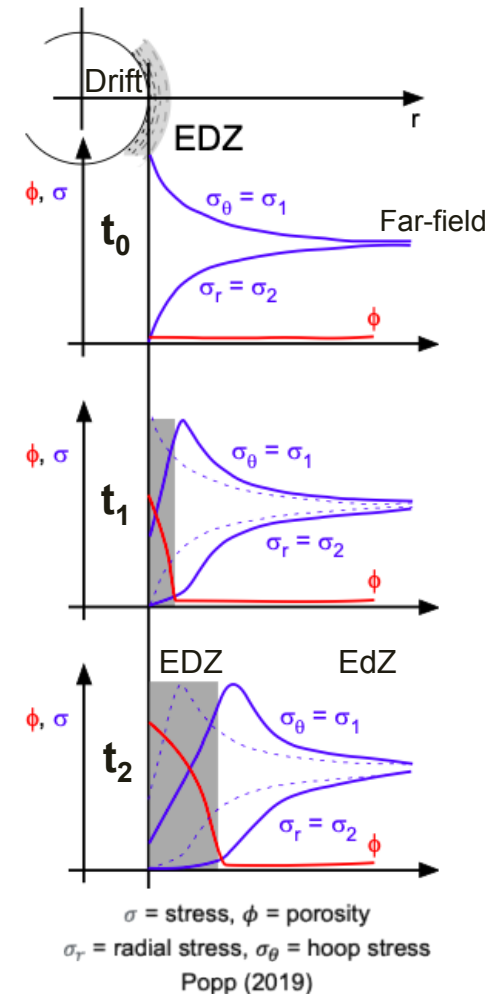
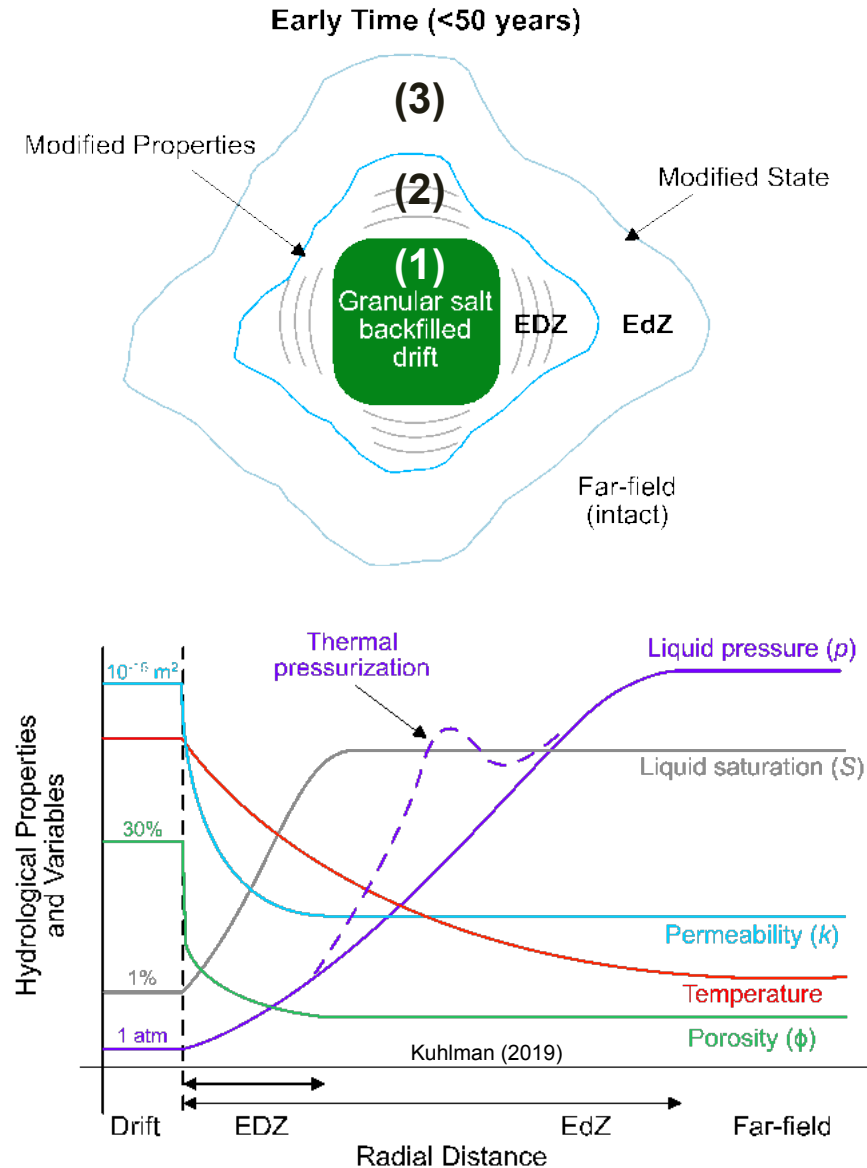
- Each Responds Differently to Heat & Pressure

* Krumhansl (2000); Permian was 252 – 299 million years ago

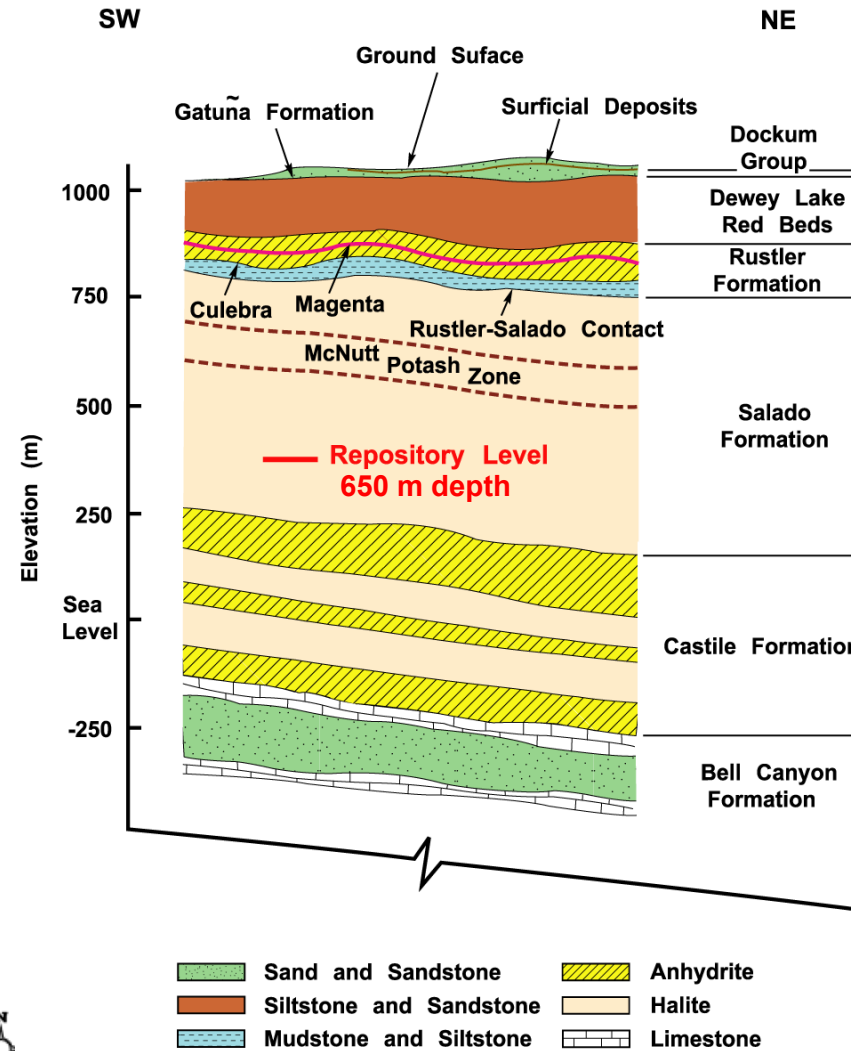
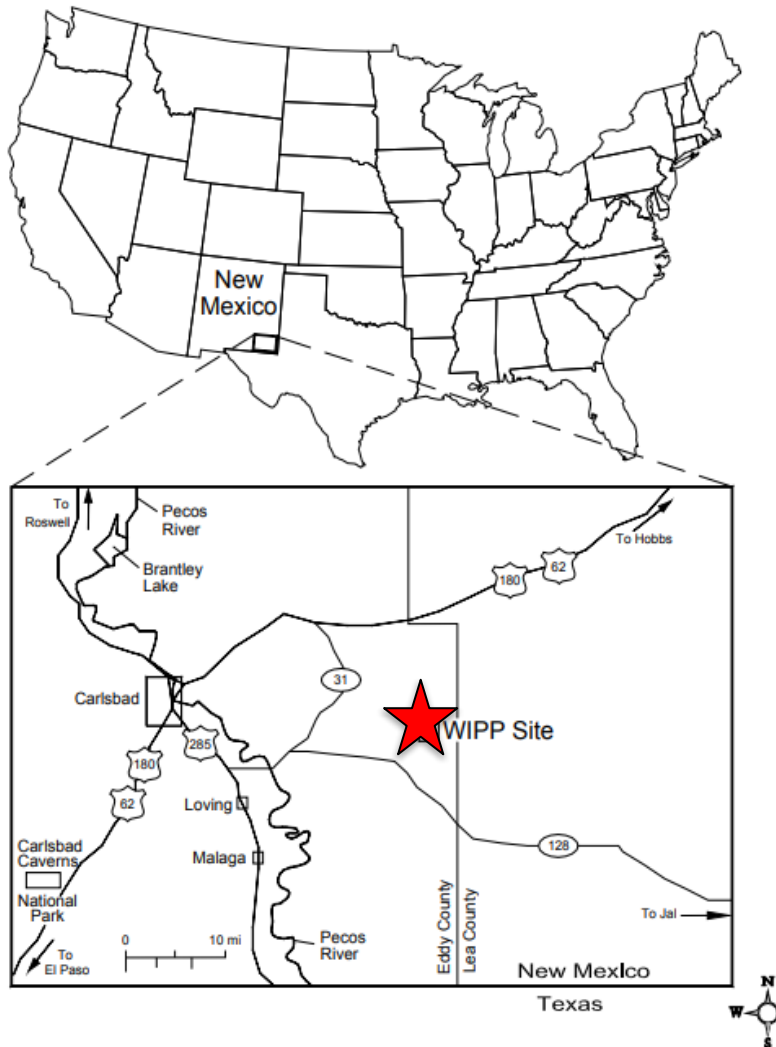
Definitions of Fundamental Processes

- Salt Repository Regions*
 1. Backfilled drift
 2. Excavation Damaged Zone (EDZ)
 3. Excavation disturbed Zone (EdZ)
- Open-Drift and Early Time
 - $\Delta\sigma \rightarrow \text{EDZ} \rightarrow \Delta\phi$ and Δk
- Later Time (>10 – 1,000 years)
 - Backfill \rightarrow intact salt
 - EDZ \rightarrow intact salt
 - EdZ shrinks significantly

*Davies & Bernier (2005)



Brine Availability Test in Salt at the Waste Isolation Pilot Plant



WIPP is a repository for TRU (transuranic) waste

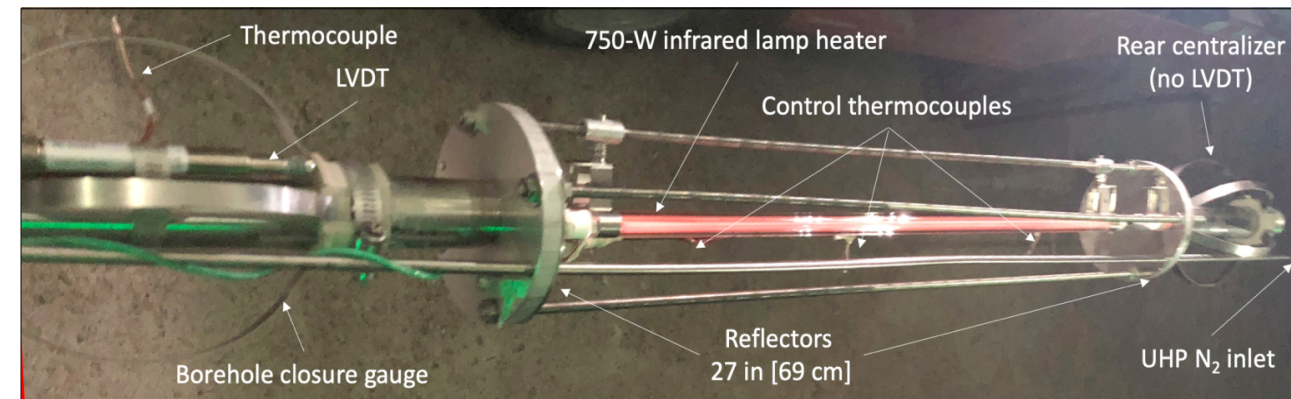
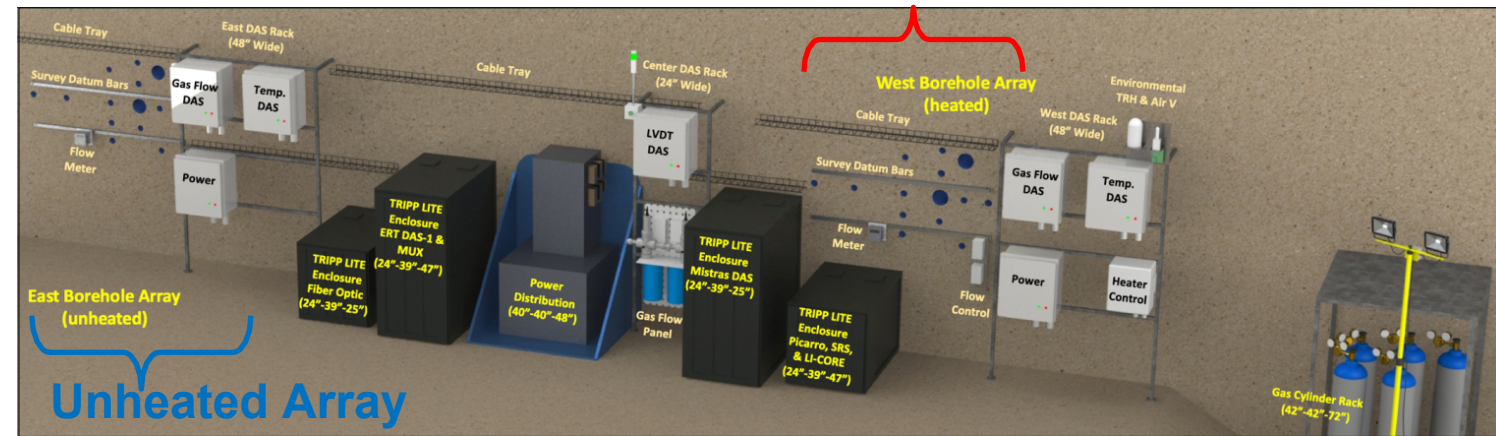


- WIPP has been operating since 1999
- CBFO provides access to WIPP for Brine Availability Test in Salt (BATS)

BATS 1

- Two Arrays (14 boreholes each)
- Behind HP packer
 - Circulate dry N₂
 - Quartz lamp heater (750 W)
 - Borehole closure gage
- Samples / Analyses
 - Gas stream (natural / applied tracers and isotopic makeup)
 - Liquid brine (natural chemistry and natural / applied tracers)
 - Cores (X-ray CT at NETL)
- Cement Seals
 - Sorel cement + Salt concrete: strain & temperature
- Geophysics
 - 3× Electrical resistivity tomography (ERT)
 - 3× Acoustic emissions (AE)
 - 2× Fiber optic distributed strain / temperature sensing

Heated Array

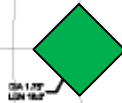


BATS 1 Borehole Arrays



AE sensors on de-centralizers

Thermocouples (T1-2)



Diamonds = grouted



Circles = not grouted/packer

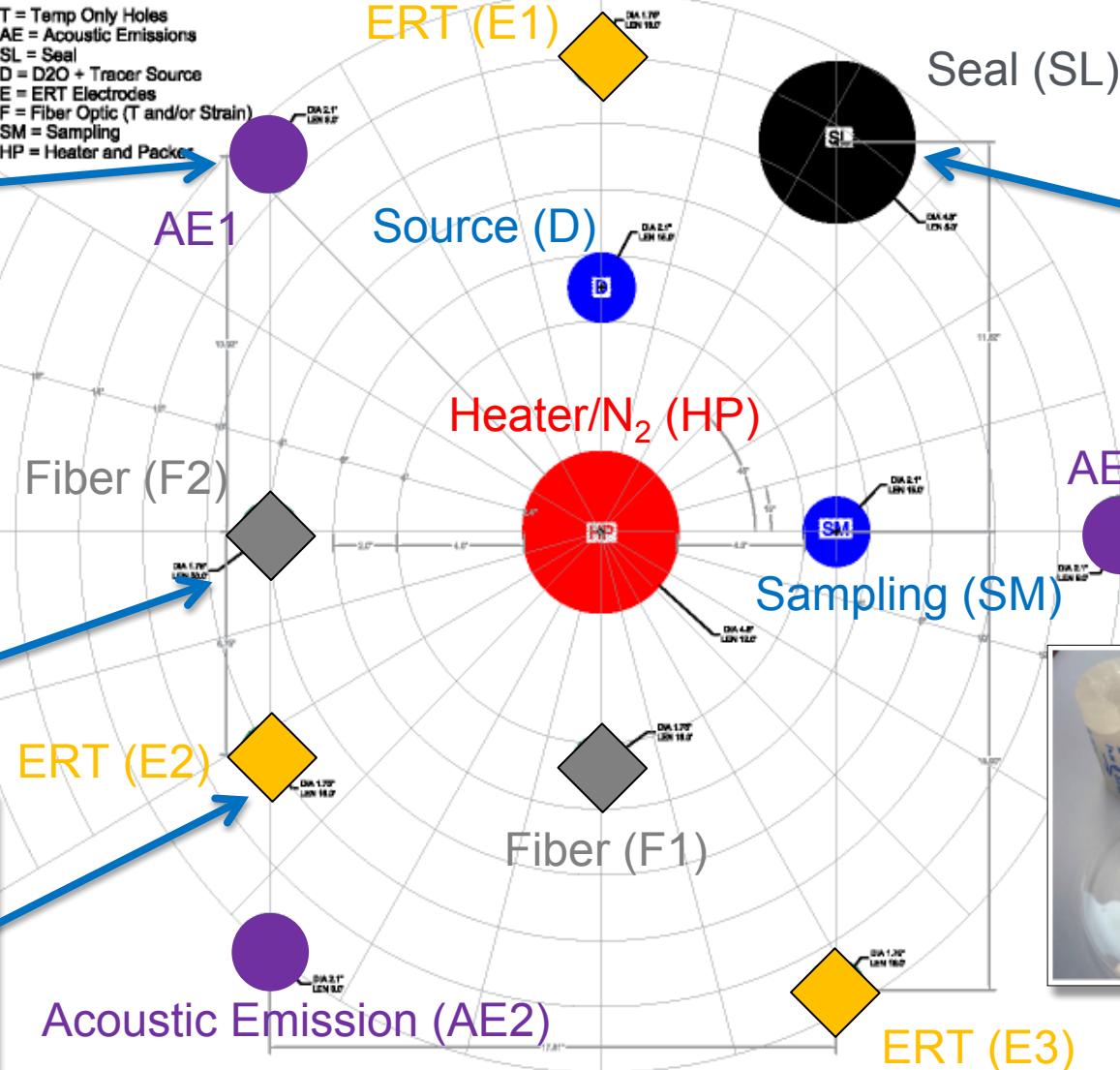


Fiber optic DAS/DST

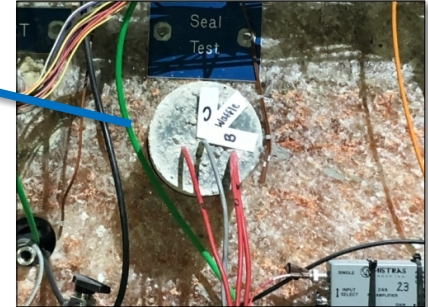


ERT controller

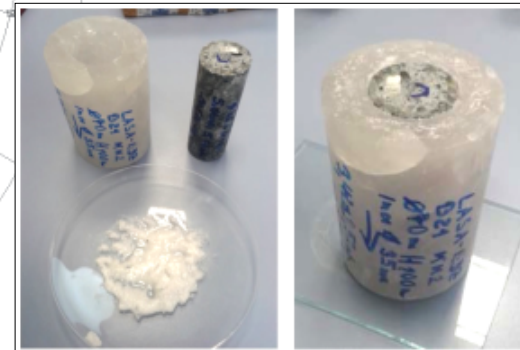
T = Temp Only Holes
AE = Acoustic Emissions
SL = Seal
D = D2O + Tracer Source
E = ERT Electrodes
F = Fiber Optic (T and/or Strain)
SM = Sampling
HP = Heater and Packer



Lab-made seal installed in borehole subsequently sealed behind packer



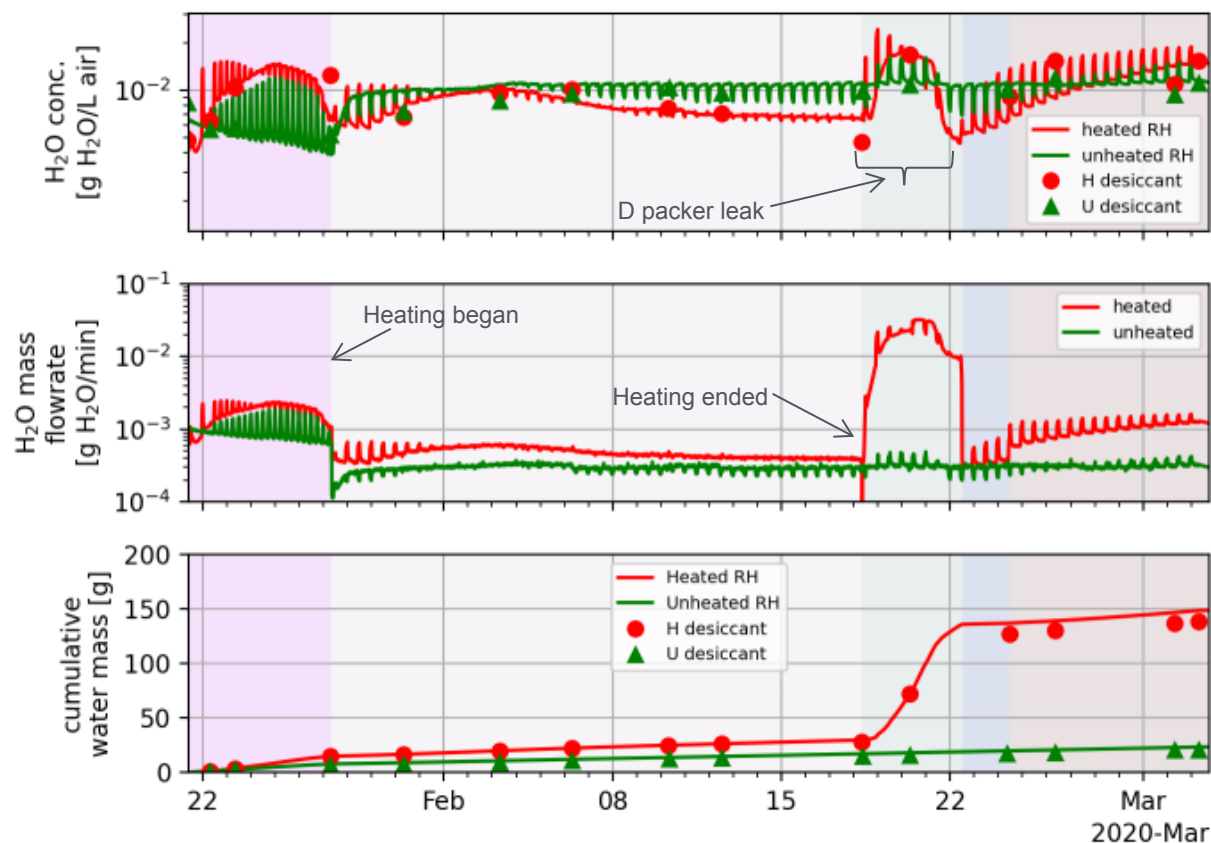
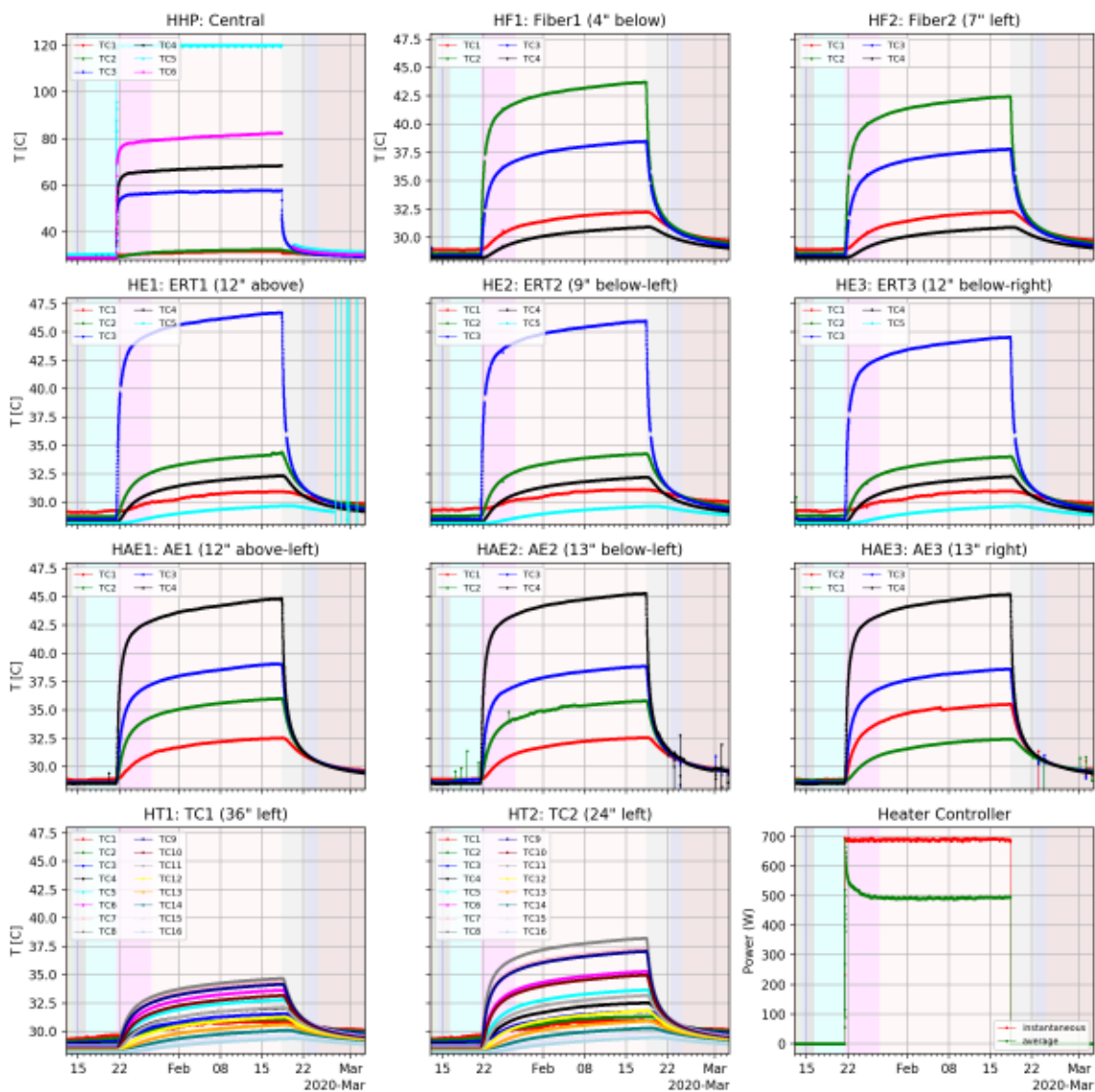
Field (BATS)
Lab (GRS)



Czaikowski et al. (2016)

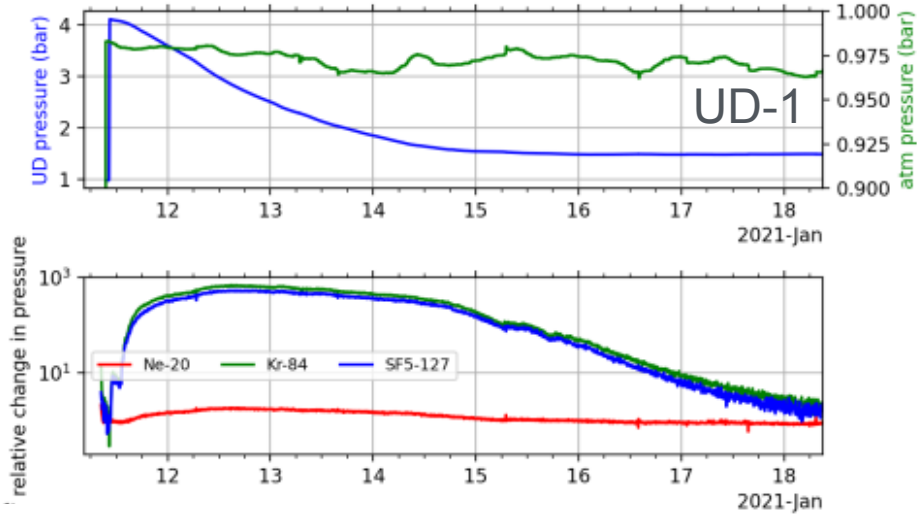
(Borehole layout drawing by WIPP TCO)

BATS 1a (Jan-Mar 2020): Temperature and Brine Inflow

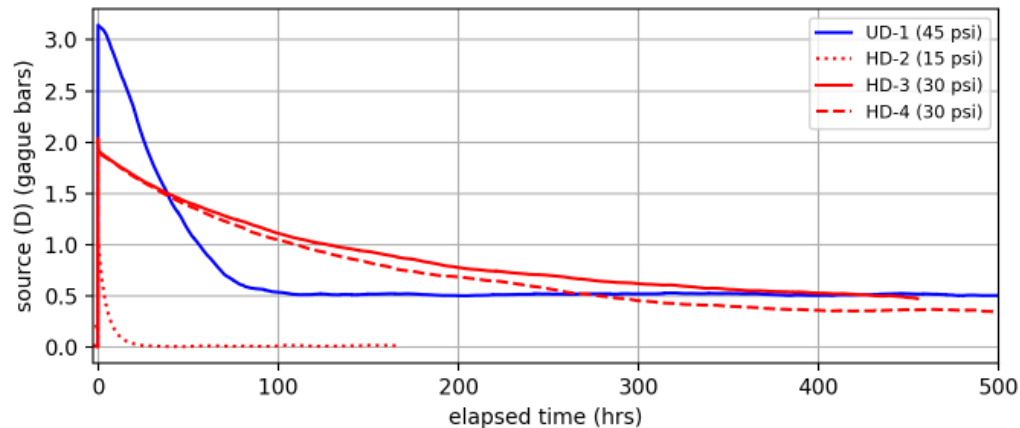


BATS 1b Gas Tracer Tests (2021)

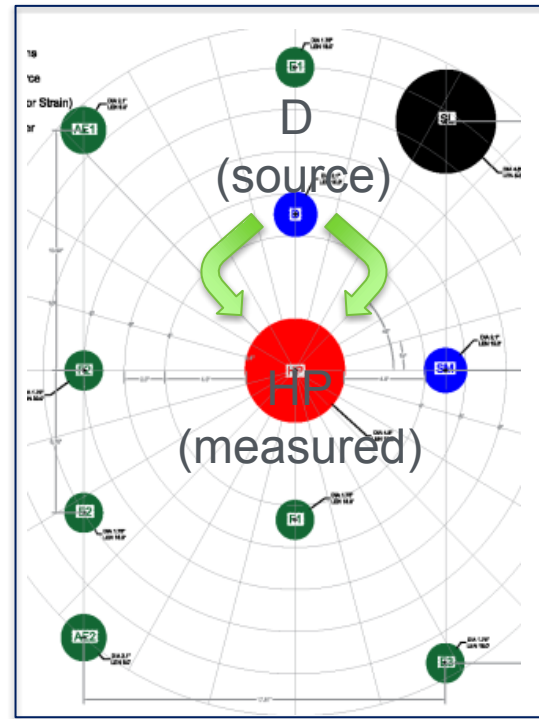
Unheated array test



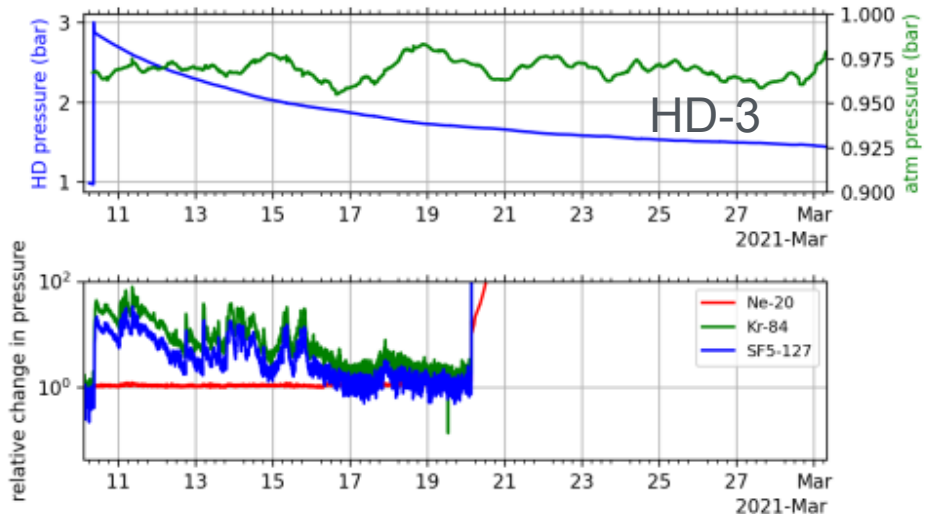
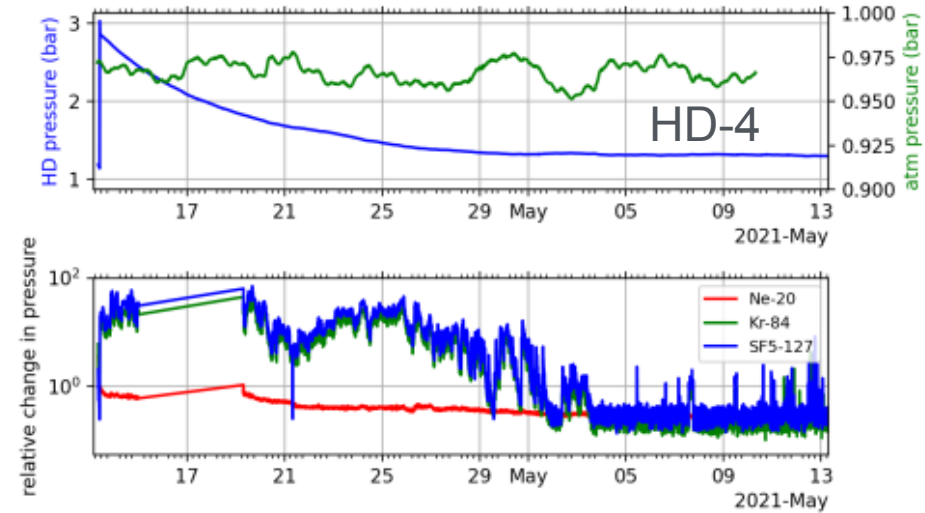
Pressure responses of all tests



Tracer gas:
5% Ne
5% Kr
5% SF₆
85% N₂

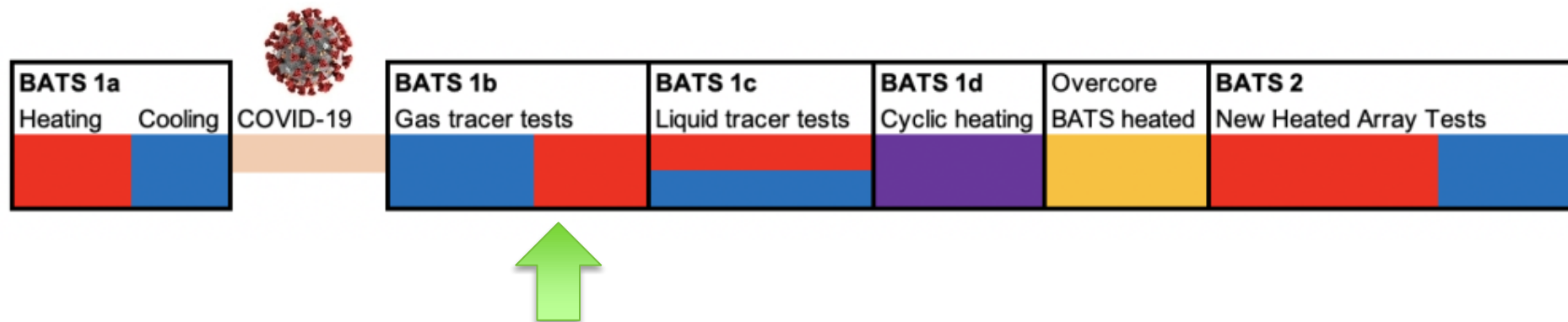


Heated array tests (before heating)

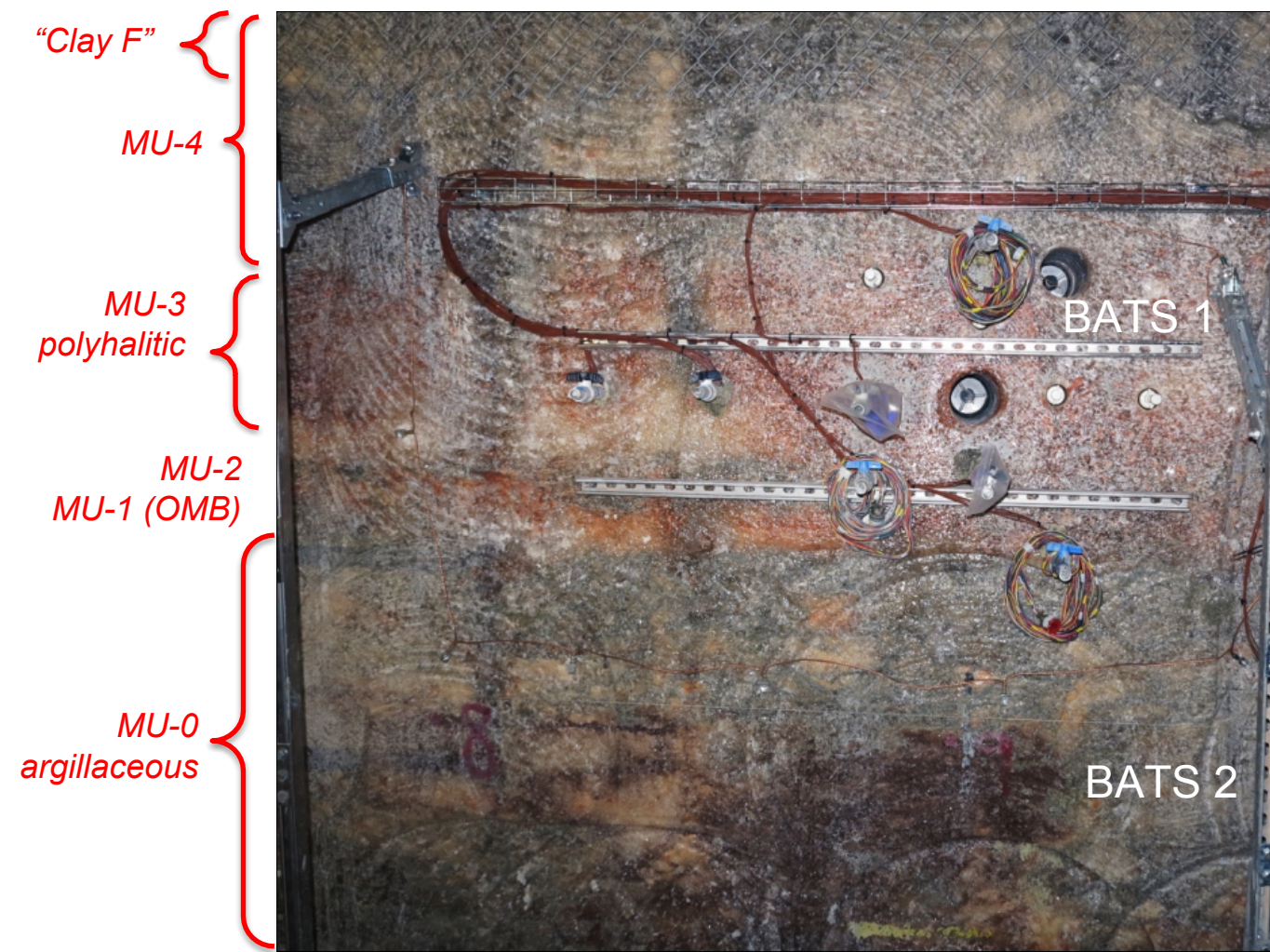


BATS 1-2

- BATS 1s shakedown test (2018)
- BATS 1a heated phase (Jan-Mar 2020)
- COVID-19
- Gas & liquid tracer tests (Jan-June 2021)
- Cyclic heating (summer 2021)
- New BATS 2 boreholes (October 2021)
 - Similar heater test in new boreholes

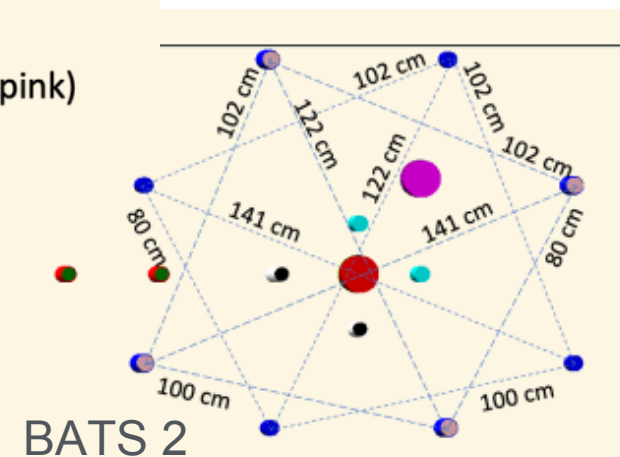
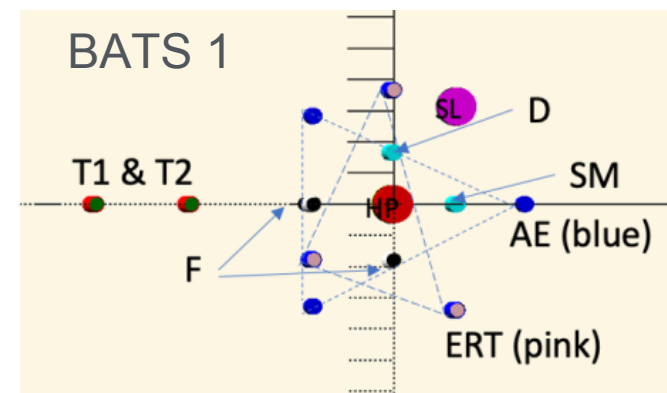


BATS 1 vs. 2 Locations



■ BATS 2

- Map Unit 0 (BATS 1 in MU-3)
- ~10 ft down the drift
- ERT / AE moved out

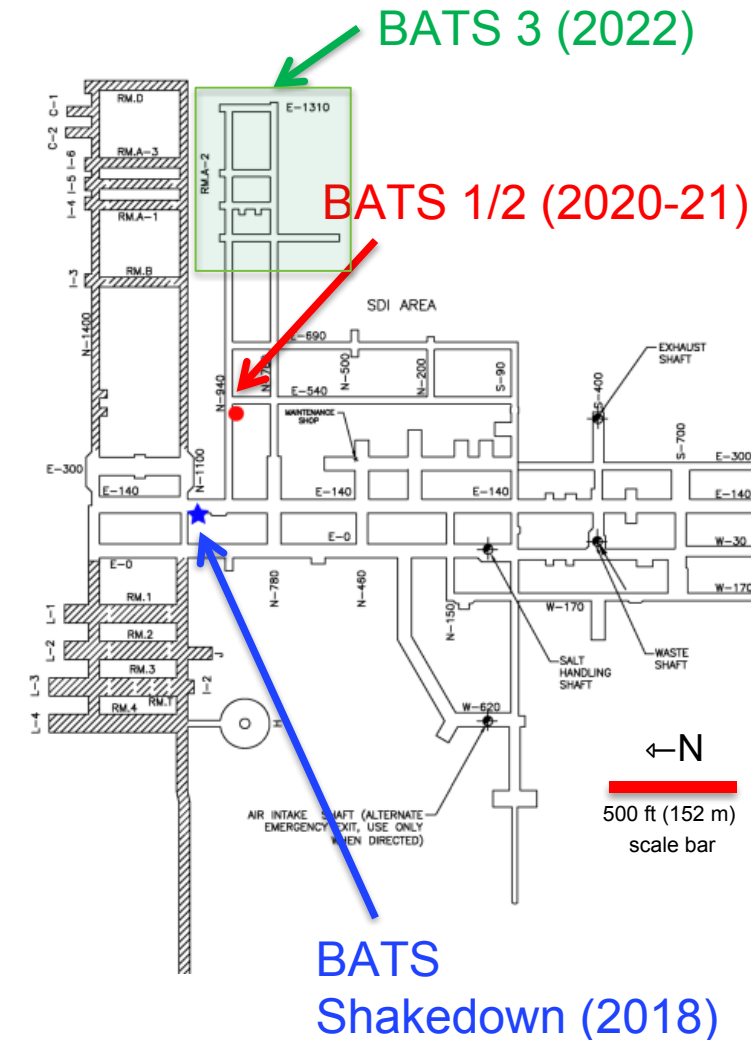


Minimize time from drilling to completion and heating

BATS 3 Plan

- BATS 1 & 2: coordinated around central borehole
 - Interference between tests
 - ERT vs. thermocouples, ERT vs. AE
 - EDZ from 14 boreholes
- BATS 3 will be more “distributed”
 - Beginning of an Underground Research Lab (URL) in salt
 - New infrastructure
 - CONEX box (dust control, lighting), internet, ground control
 - Decoupled smaller tests deeper into SDI area
 - Sealed heated borehole
 - Long-term heated borehole
 - AE during drilling (EDZ development)
 - Epoxy injection into drift EDZ fracture network
 - Cementitious EBS / seals experiments
 - Gas and brine permeability $k(\sigma, T)$

Layout of WIPP North End



Up Next:



Salt Disposal Research Session

9:15 – 9:30	Introduction	Kuhlman
9:30 – 9:42	DECOVALEX	Jayne
9:42 – 9:54	Isotope Modeling in BATS	Guiltinan
9:54 – 10:06	Lab Brine Migration	Janicke
10:06 – 10:18	Geophysics monitoring	Wang
10:18 – 10:30	THMC Modeling	Tounsi
10:30 – 10:42	International	Mills

