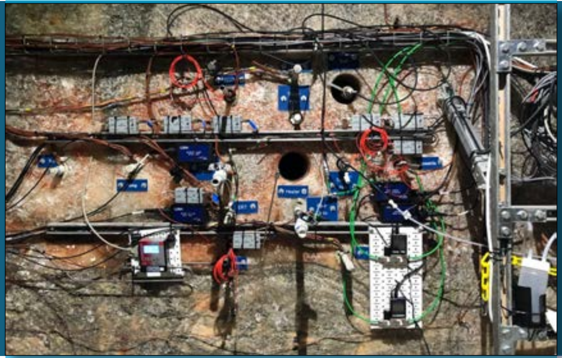
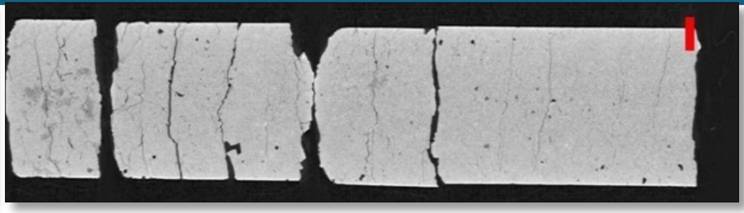
Brine Availability Test in Salt (BATS) at WIPP





Kris Kuhlman

Sandia National Laboratories

American Nuclear Society Carlsbad Chapter, Oct 16, 2019

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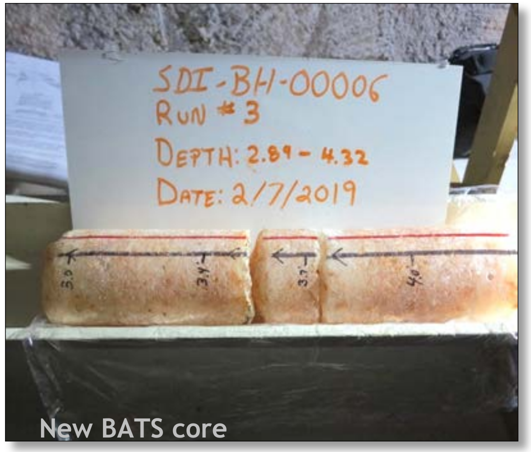
SAND2019-12447 PE

What Are We Doing?

Brine Availability Test in Salt at WIPP (BATS)

Monitoring brine distribution, inflow, and chemistry from heated salt using geophysical methods and direct liquid & gas sampling.

Status: Boreholes drilled (April), instrumentation installed (Sept), test is ready to begin.



New BATS core


New BATS boreholes


Nearly ready BATS test drift

Who Are We?

BATS funded by DOE Office of Nuclear Energy (DOE-NE) Spent Fuel and Waste Science and Technology program

Sandia National Laboratories (SNL)

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WIPP funded by DOE Office of Environmental Management (DOE-EM)

Motivation and Background

Why are we doing this?

Why Salt?

Long-term benefits

- Low connected porosity (0.1 vol-%) and permeability ($\leq 10^{-22}\ \mathrm{m}^2$)
- High thermal conductivity ($\sim 5\ \mathrm{W/(m \cdot K)}$)
- No flowing groundwater (≤ 5 wt-% water)
- Hypersaline brine is biologically simple, has less-stable colloids
- Cl ($\sim 190\ \mathrm{g/L}$) in brine reduces criticality concerns
- Excavations, damage, and fractures will creep closed
- Mined salt reconsolidates and heals to intact salt properties

Near-field short-term complexities

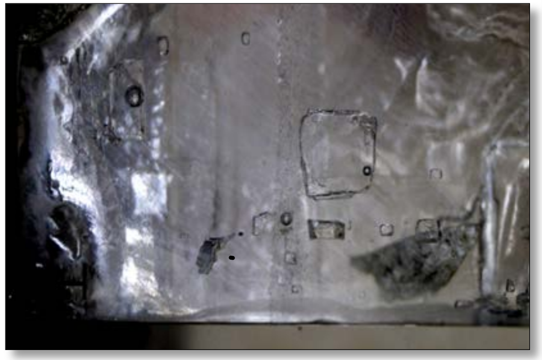
- Hypersaline brine is corrosive
- Salt is very soluble in fresh water
- Brine chemistry requires Pitzer
- Salt creep requires excavation maintenance

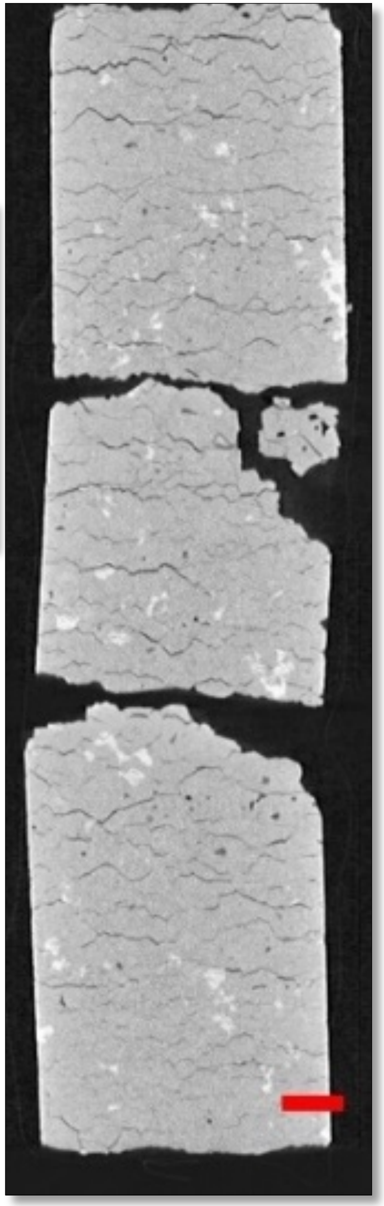
Why Focus on Brine in Salt?

- No flowing groundwater, but not dry (≤ 5 wt-% water)
- Water sources in salt
  1. Disseminated clay (<5% total; ~25 vol-% brine)
  2. Intragranular brine (fluid inclusions; 1 to 2 vol-%)
  3. Intergranular brine (between salt crystals; ~0.1%)
- Total brine content correlates with total clay content
- Three types of water respond differently to heat
- Three waters have different chemical / isotopic composition
- Porosity (#3) increases due to damage → primary flow path

Q: How do 3 water types contribute to *Brine Availability?*

Fluid inclusions



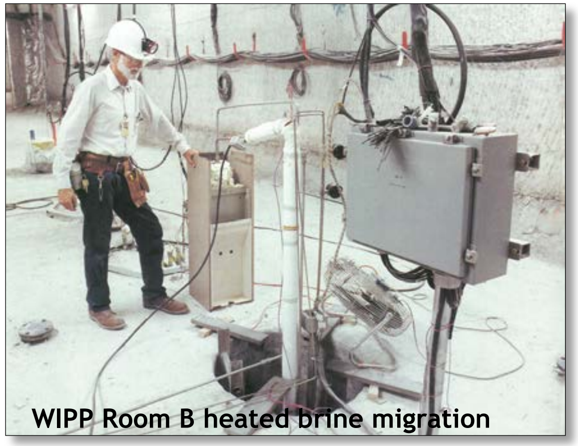


20 mm scale bar

Why is Brine Important in a Repository?

Brine Availability: *Distribution of brine in salt & how it flows to excavations*

- Initial conditions to post-closure safety assessment
  - Brine migration and re-distribution
  - Evolution of disturbed rock zone (DRZ) porosity and permeability
- Brine causes corrosion of waste package / waste form
- Brine is primary radionuclide transport vector
- Liquid back-pressure can resist drift creep closure



WIPP Room B heated brine migration

WIPP Room J canister tests

WIPP Room Q brine inflow

WIPP brine permeability testing

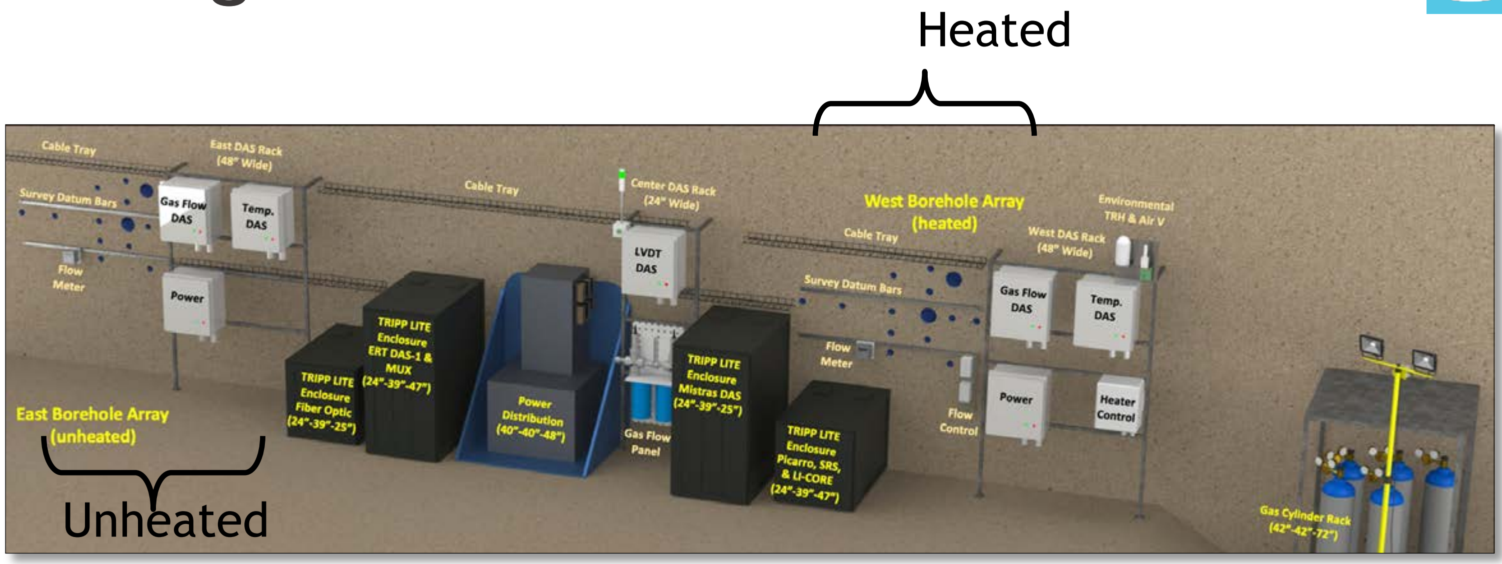
Why a Heated Test?

Impact heat-generating radioactive waste would have on salt

How do 3 brine types respond to heat
- Thermal expansion of brine
- Fluid inclusions move under a thermal gradient
- Hydrous minerals dry out

How does salt mechanically respond to heating
- Creep is accelerated at higher temperatures
- Rapid changes in temperature cause damage

What Data are We Collecting?



Two arrays: Heated / Unheated

Behind packer

- Circulate dry gas
- Quartz lamp heater (750 W)
- Borehole closure gage

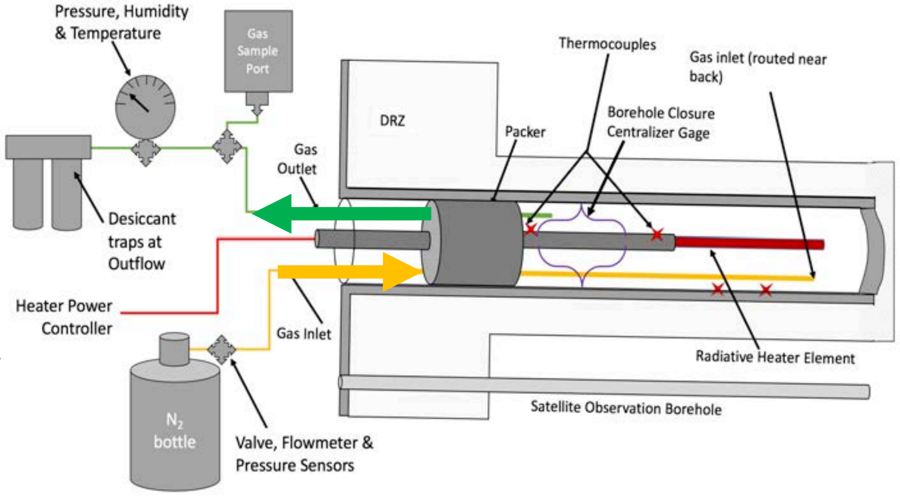
Samples / Analyses

- Analyze gas stream (natural / applied tracers and isotopic makeup)
- Collect liquid brine (natural chemistry and natural / applied tracers)
- Collect cores (X-ray CT and fluorescence at NETL)

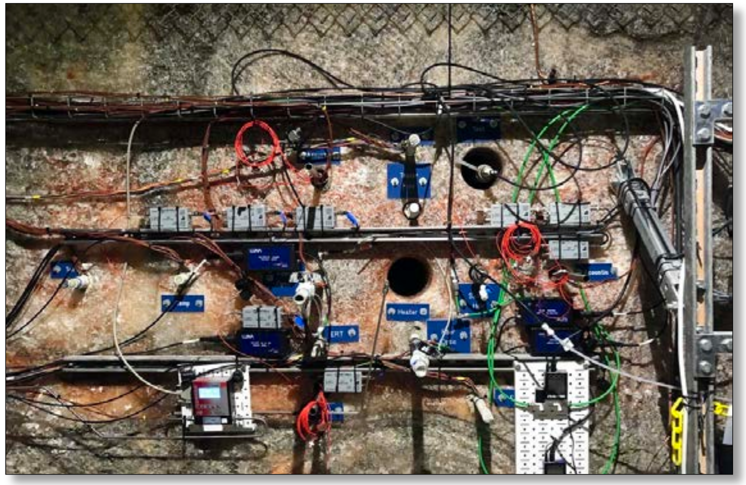
Geophysics

- 3× Electrical resistivity tomography (ERT)
- 3× Acoustic emissions (AE) / ultrasonic travel-time tomography
- 2× Fiber optic distributed strain (DSS) / temperature (DTS) sensing

Cross-section central borehole



Why are These Data Useful?



Brine composition samples / H_2O isotope data
- Observe change in brine sources with temperature

Geophysics
- Map 4D evolution of **saturation** / **porosity** / **permeability**

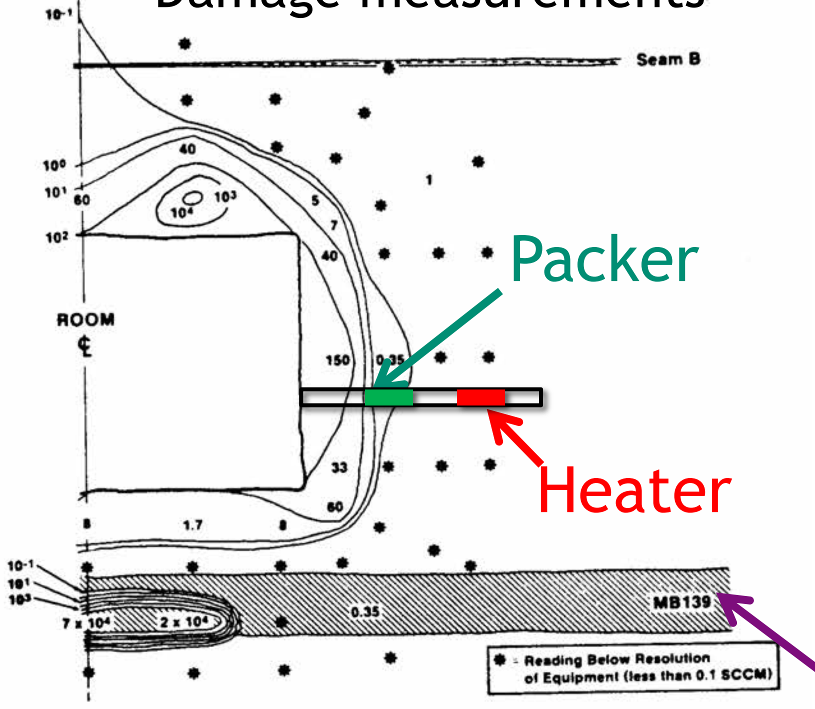
Temperature distribution
- More brine available at high temp (inclusions + hydrous minerals)
- Thermal expansion brine driving force
- Salt dry-out near borehole

Gas permeability and borehole closure
- Thermal-hydrological-mechanical evolution of salt during heating

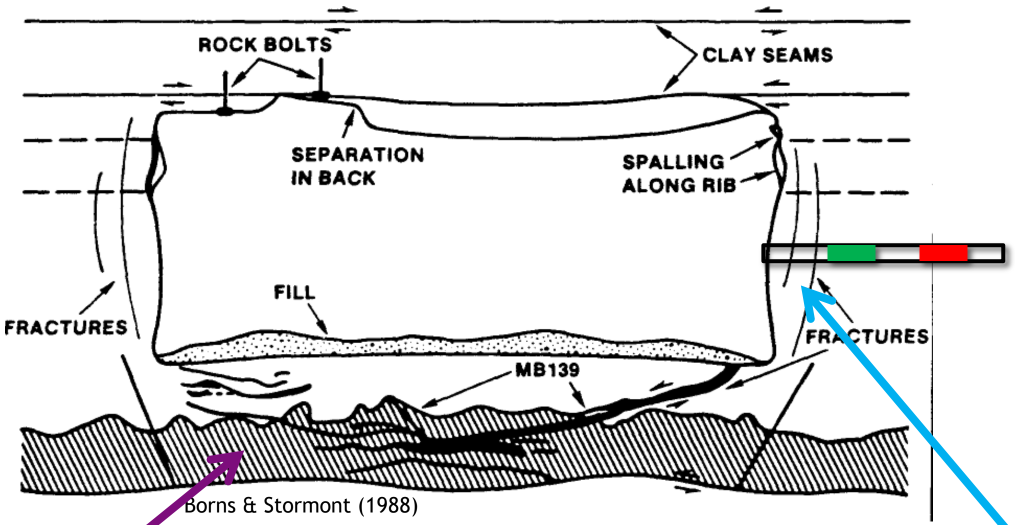
Tracer migration through salt
- Monitor brine movement through salt damage zone

Why use Horizontal Boreholes with Packers?

Damage measurements



Disturbed Rock Zone (DRZ)



BATS borehole

Near-drift vertical fractures

Anhydrite layer below floor

We want to characterize DRZ, avoiding most damaged areas

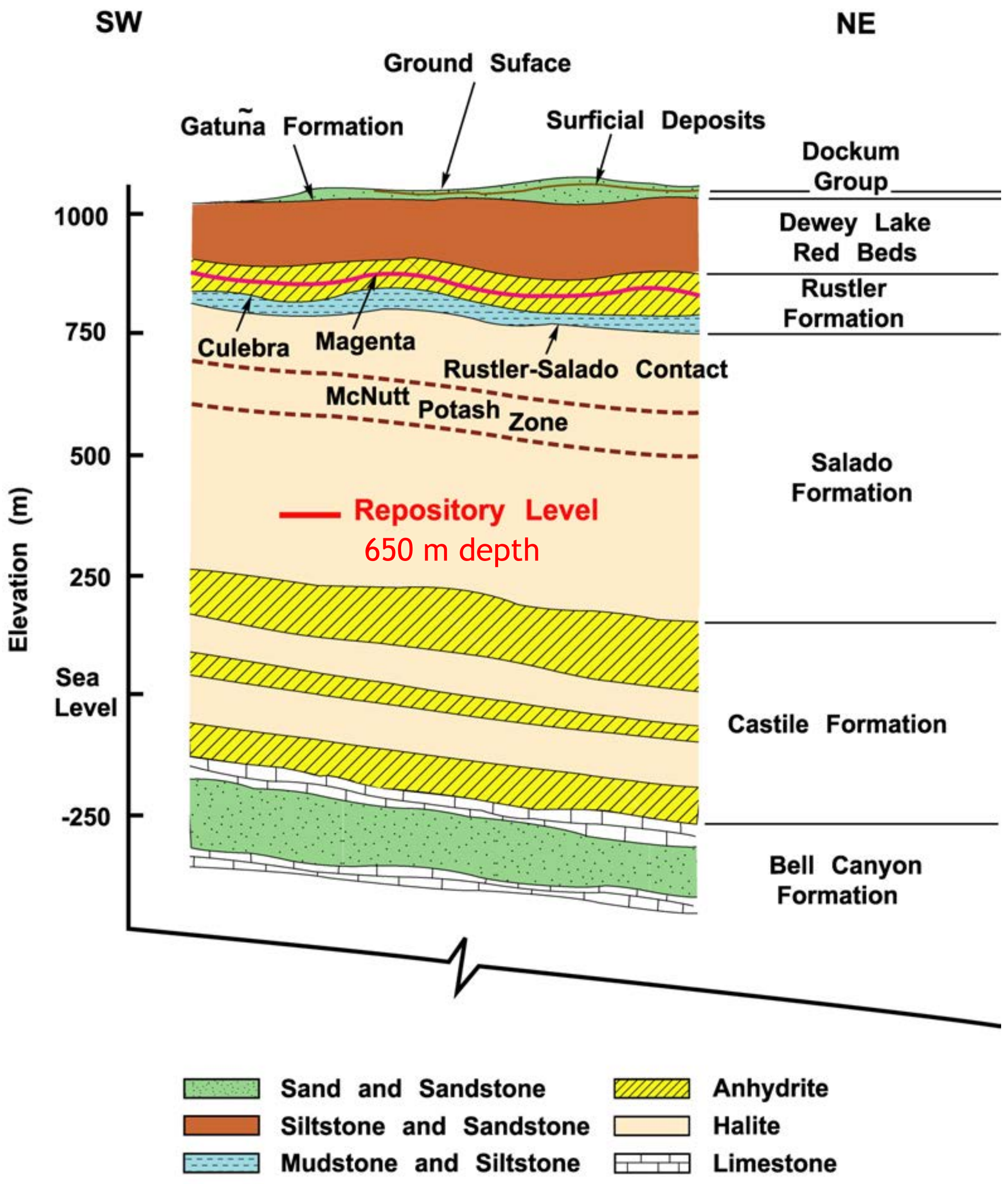
- *Horizontal borehole* avoids clay & anhydrite layers (e.g., MB139) in floor
- *Inflatable packer* isolates heater from near-drift vertical fracutres

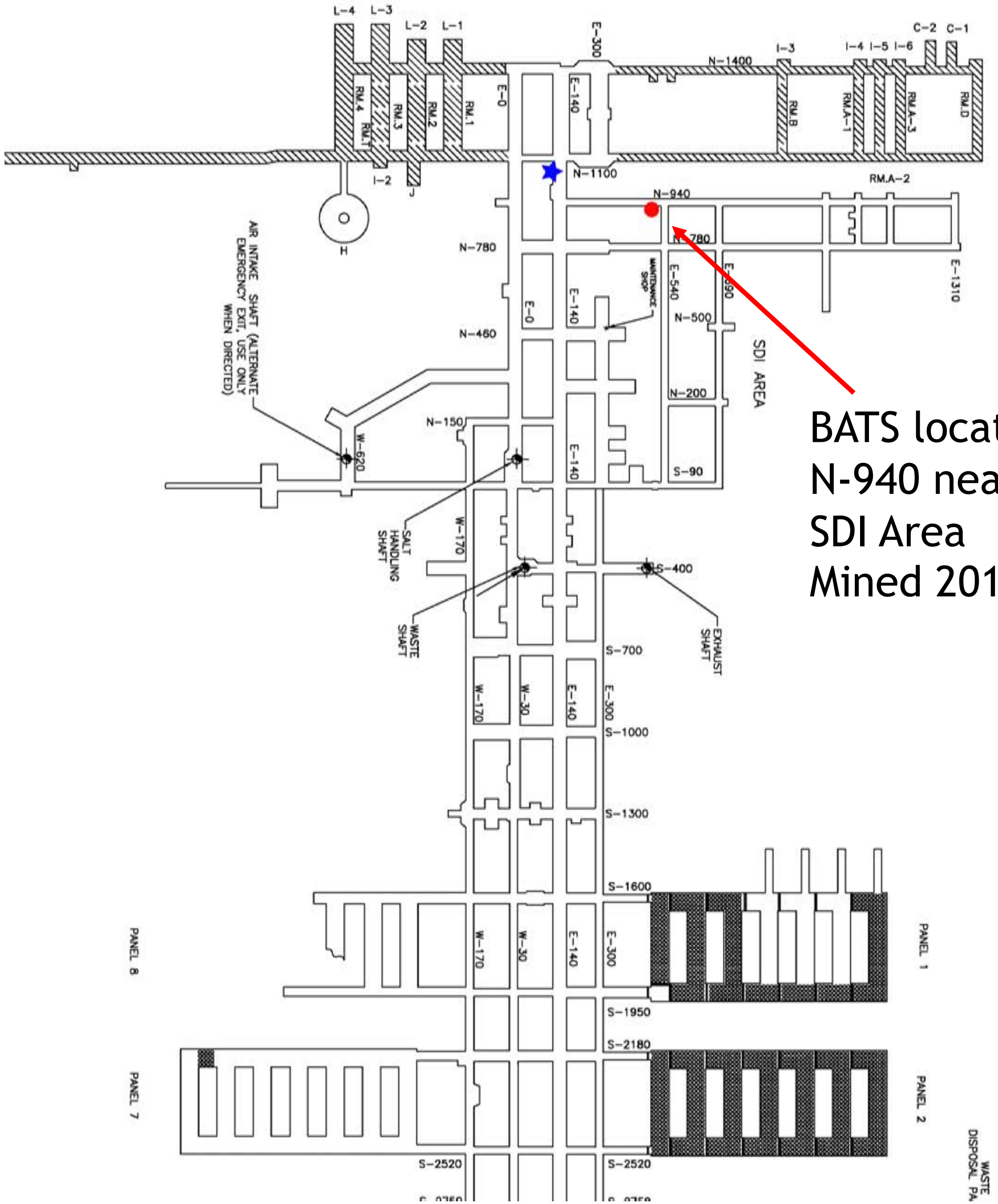
Test Details

What data will be collected?

What do we hope to learn?

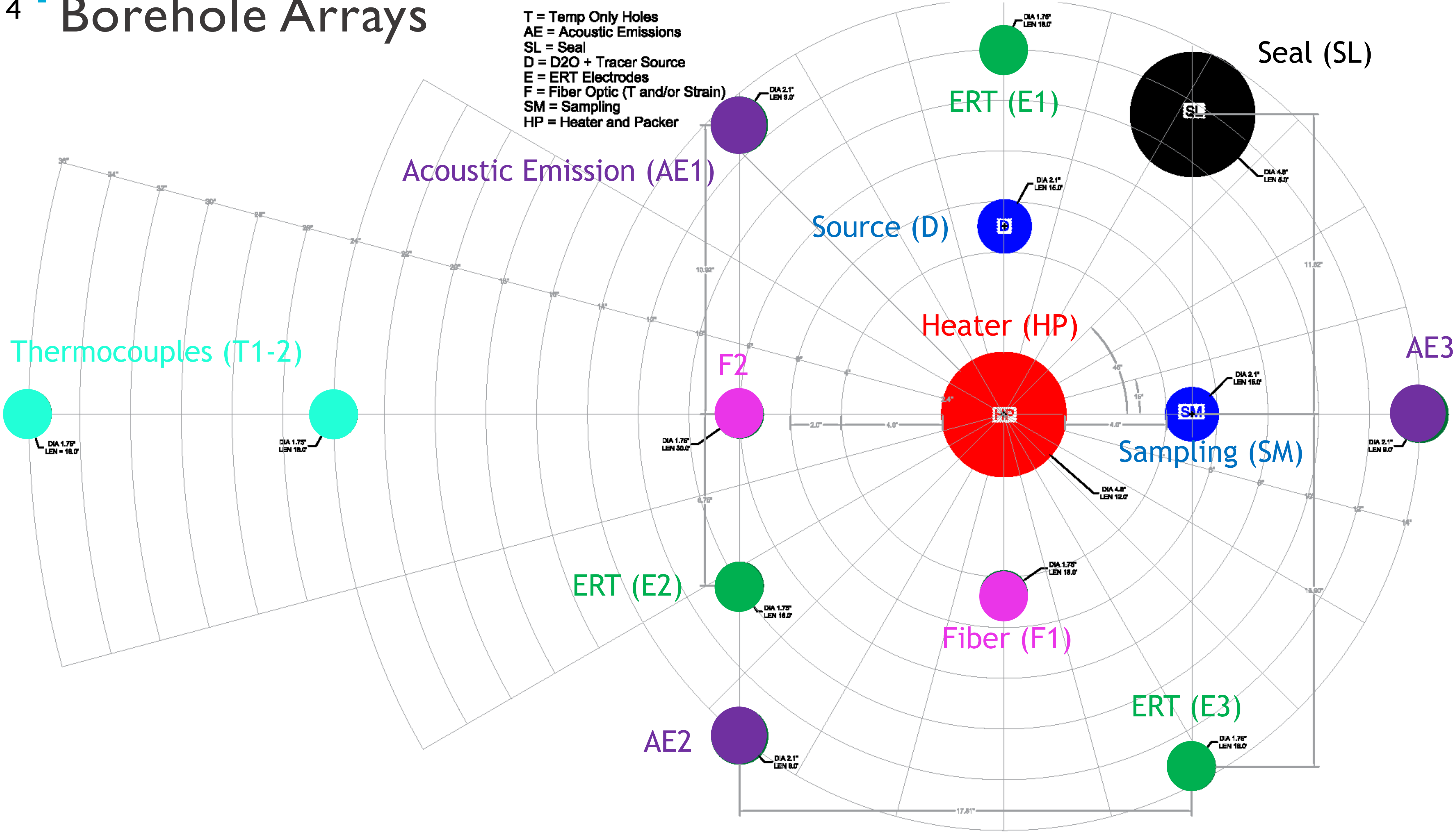
Test Location





BATS location
N-940 near E-540
SDI Area
Mined 2012

Borehole Arrays



Core Analyses

Cores from 4.8" boreholes

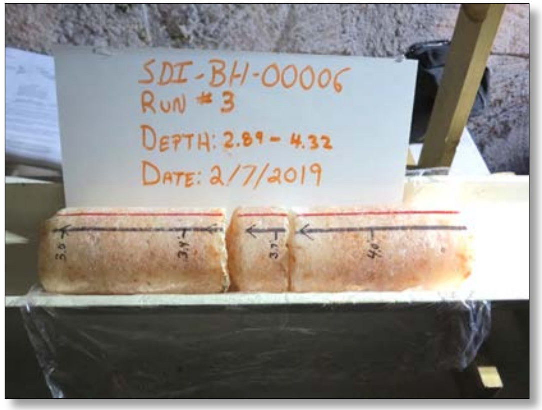
X-Ray Computed Tomography (CT)
- Medical and industrial scanners

X-Ray Fluorescence (XRF)
- Elemental composition on core surface

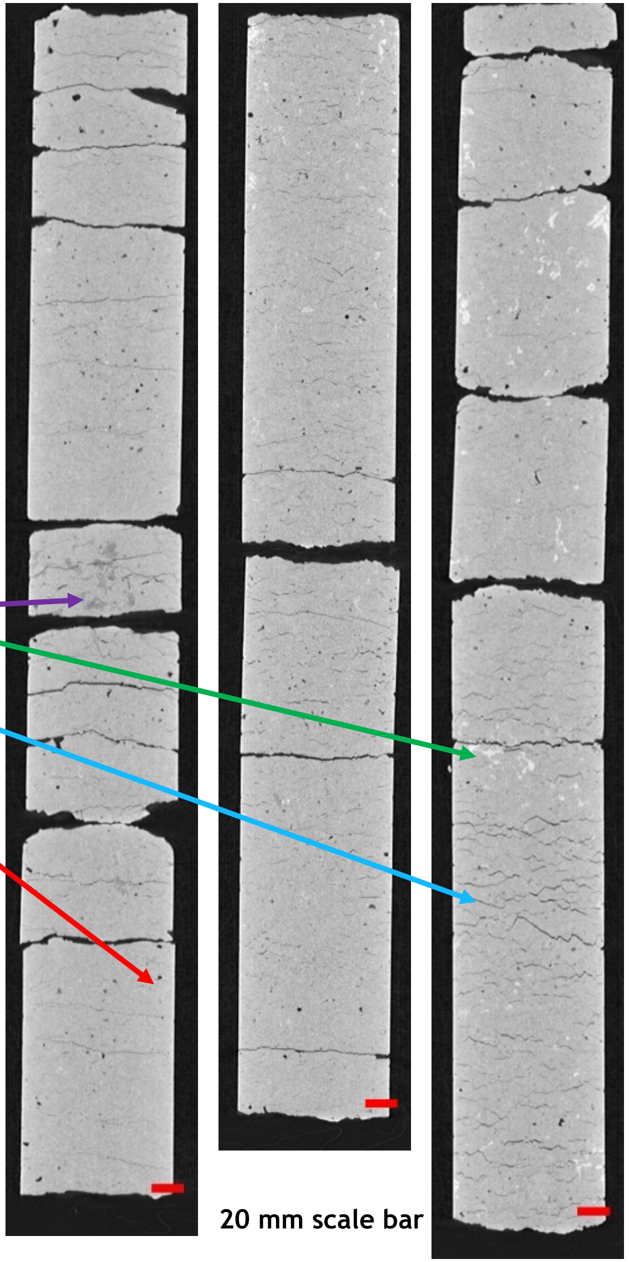
Sub-core Microstructural Observations
- Observe fluid inclusions
- Observe dislocations and salt fabric

Post-test overcore for comparison (12" core)
- X-Ray CT and microstructural observations

What type of brine & how did test change salt?



Distribution in 3D:
Clay & polyhalite
Fracture porosity
Fluid inclusions



Imaging by Dustin Crandall at National Energy Technology Laboratory (NETL)

Brine Inflow

Gas flowrate + humidity

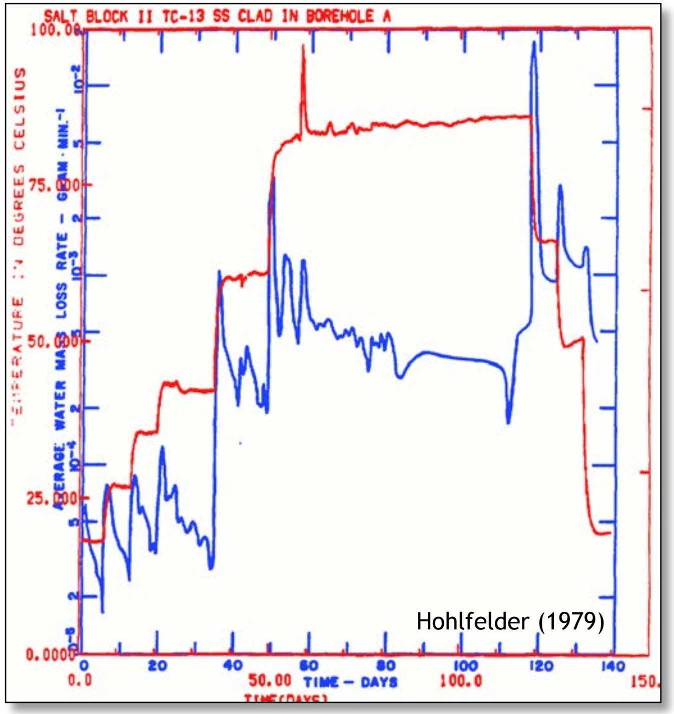
Brine inflow to boreholes

- Highest inflow rate initially
- Rate exponentially decays with time

Brine inflow jumps at $\pm\Delta T$

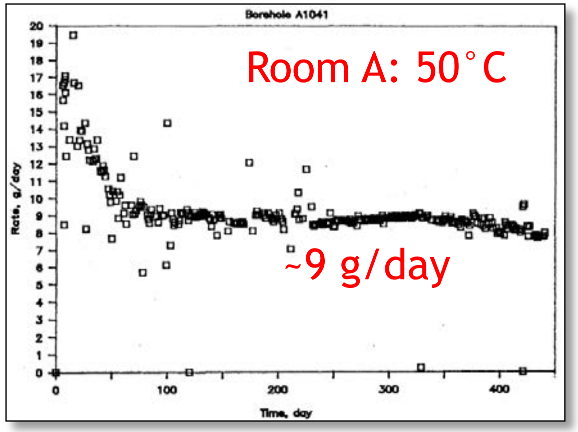
More brine at higher temperatures

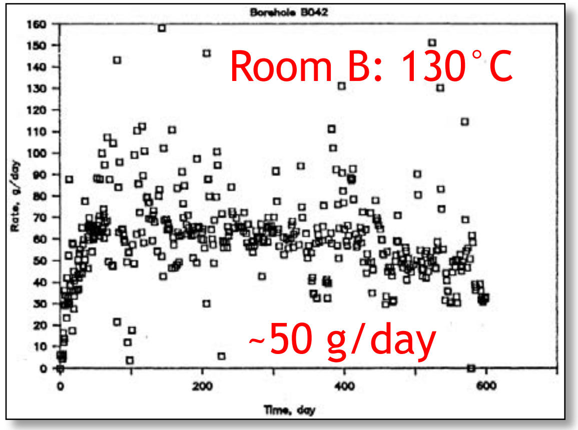
Permeability / brine saturation of salt



Salt Block II (1-m lab test)

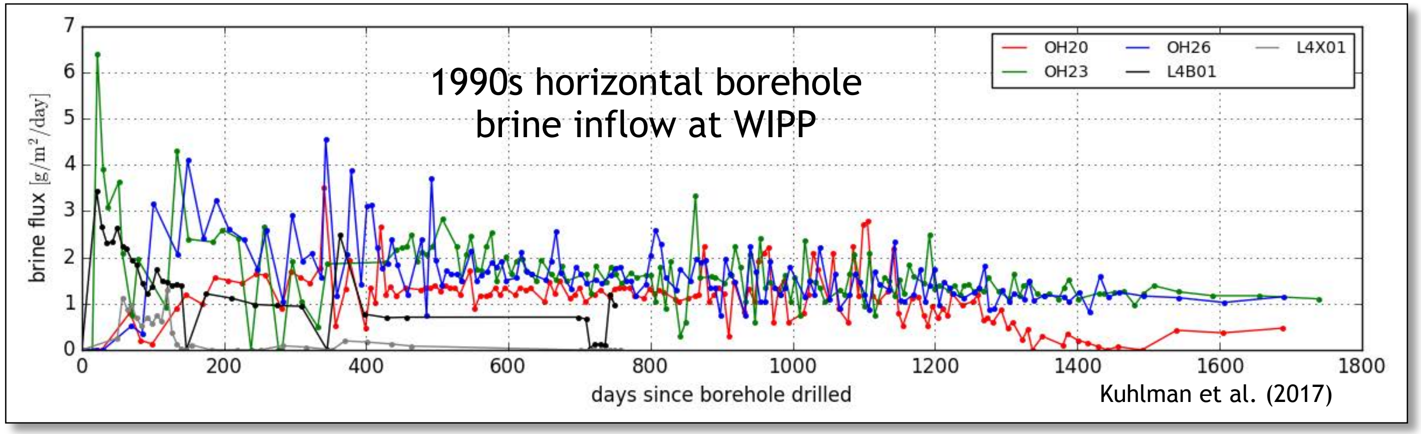
Vertical WIPP boreholes





Vertical boreholes that intersected clay layers

Nowak & McTigue (1987)



Brine Composition

<u>Liquid brine samples vacuumed from back of boreholes</u>

Distinguish sources of water in salt?

- Not all brine is same composition
- Different formations at WIPP
- "Natural" brine vs. dissolved salt

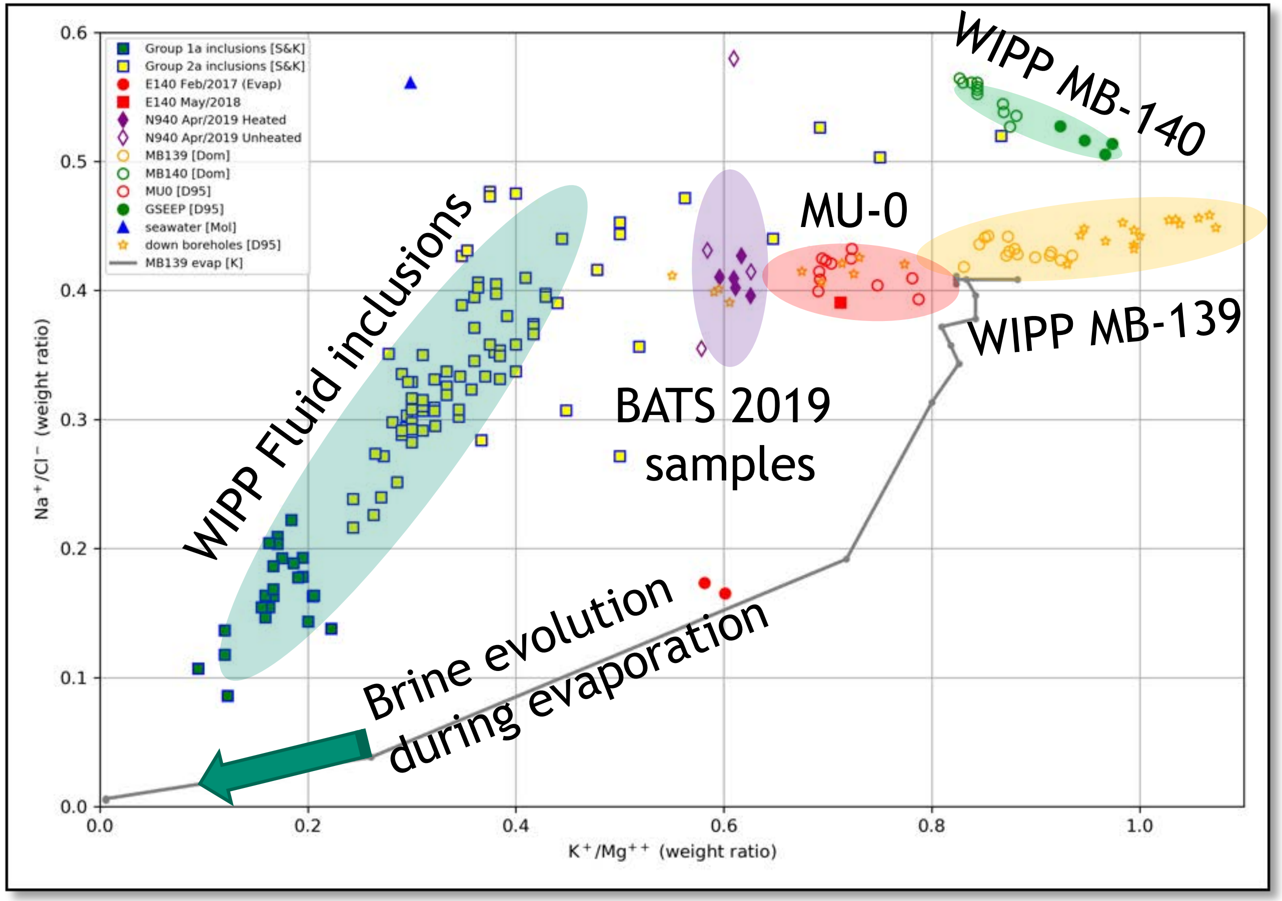
Add / monitor liquid tracers

- Perrhenate ($NaReO_4$)
- Blue fluorescent dye
- Isotopically distinct H_2O

<u>Data will inform:</u>

- Contribution of 3 brine types (brine)
- Advection / diffusion / reaction (tracers)

De-ionized water
+ WIPP salt



Gas Stream Composition

Analyze gas stream in-drift real-time

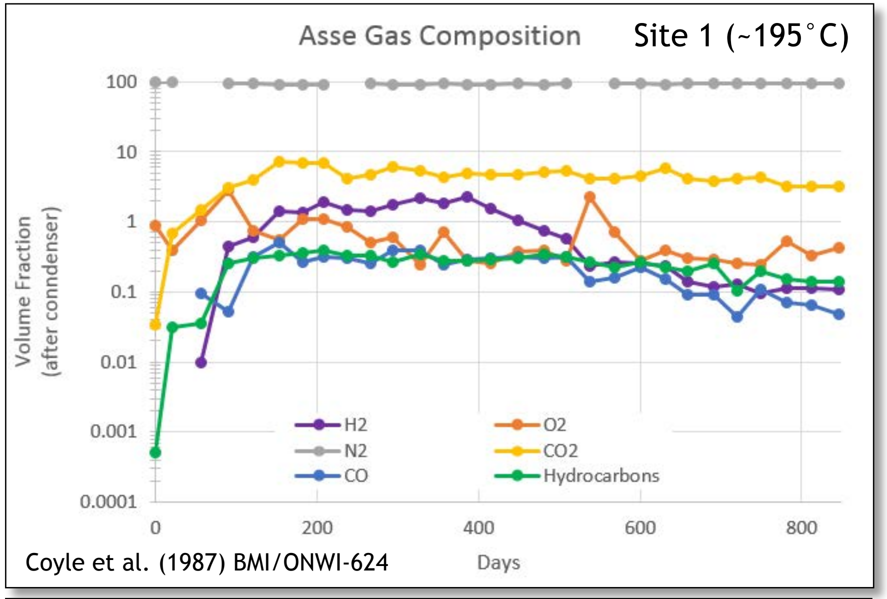
Gases derived from
- Dissolved gas in brine (~15 MPa in far field)
- Geogenic gases from salt (e.g., He & Ar)
- Added gas tracers (Xe, Ne, Kr & SF_6)

Isotopic makeup of humidity stream
- Info on brine source (fluid inclusions vs. clays)

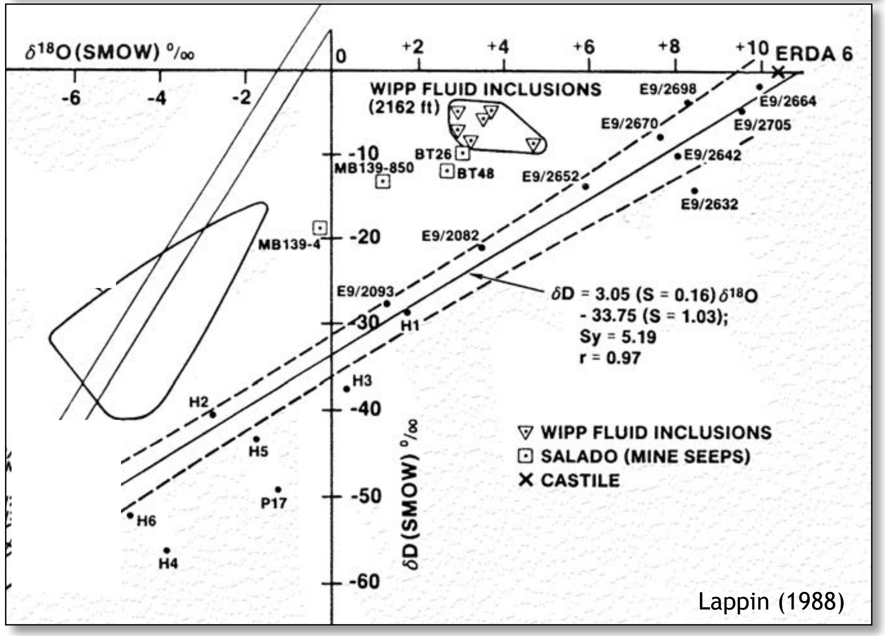
Data will inform:
- Gases produced from heating salt
- Isotopic identification of 3 brine types
- Advection / diffusion /reaction (tracer)

SRS quadrupole mass spectrometer (QMS) gas analyzer

Picarro cavity ringdown Spectrometer (CRDS)



Coyle et al. (1987) BMI/ONWI-624



Lappin (1988)

Acoustic Emissions (AE)

Listen to salt with piezoelectric transducers

Passive AE

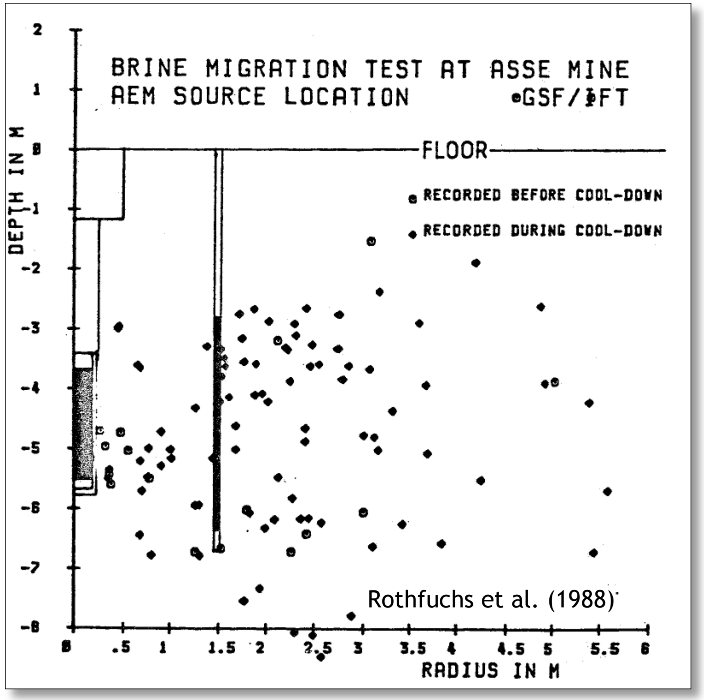
- Salt cracking during heat up & cool-down
- Triangulate AE sources around heated borehole
- AE correlated with permeability increases

Active AE

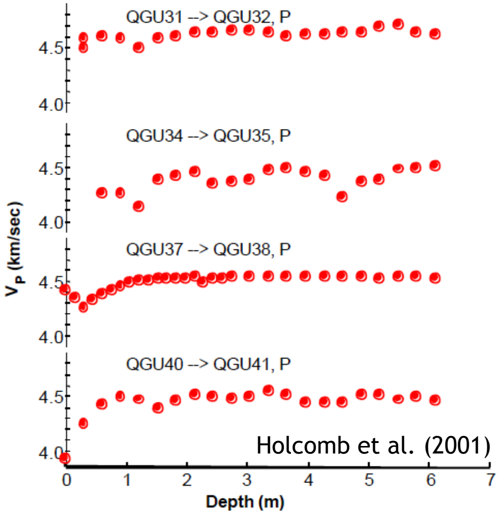
- "Ping" sensors while listening, estimate travel times
- Lower velocity in damaged rock

Data will inform:

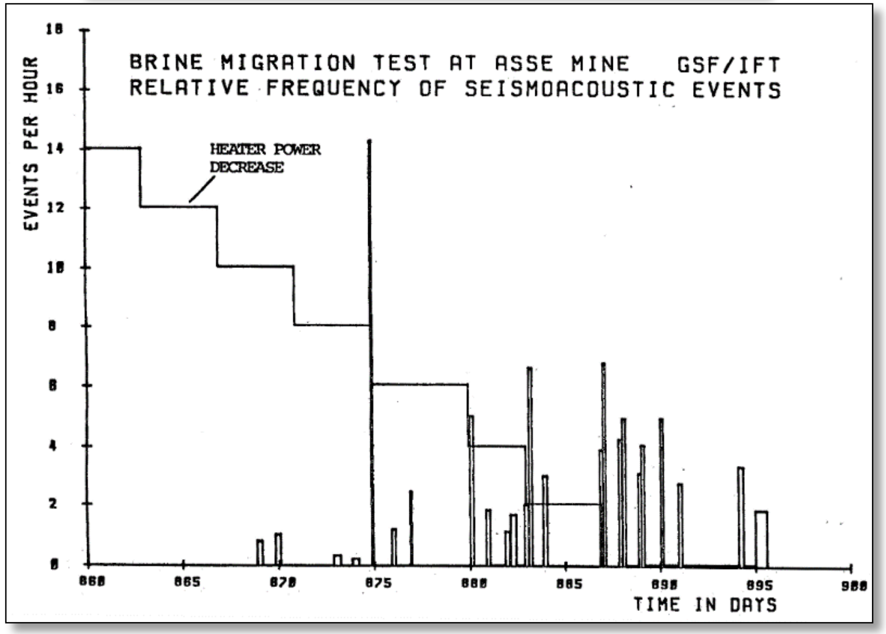
- Where & when damage occurs
- Estimate damage extent
- Monitor damage evolution



Rothfuchs et al. (1988)

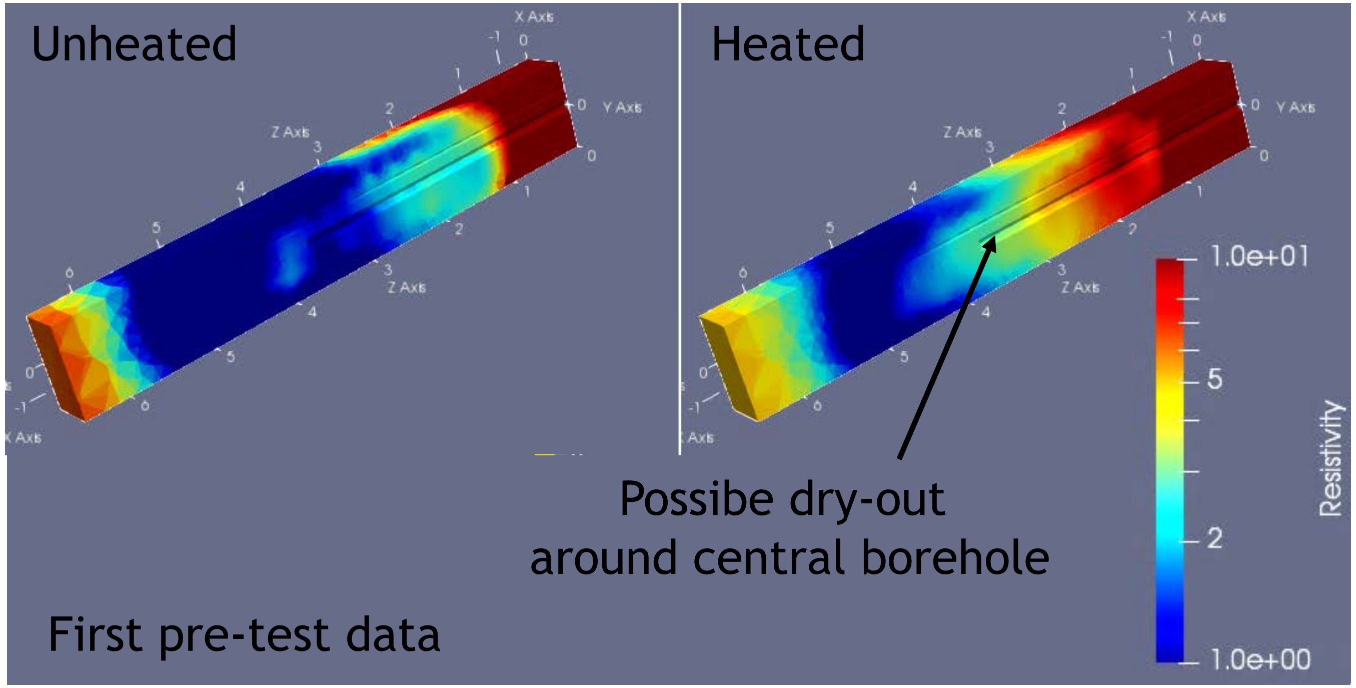


Holcomb et al. (2001)

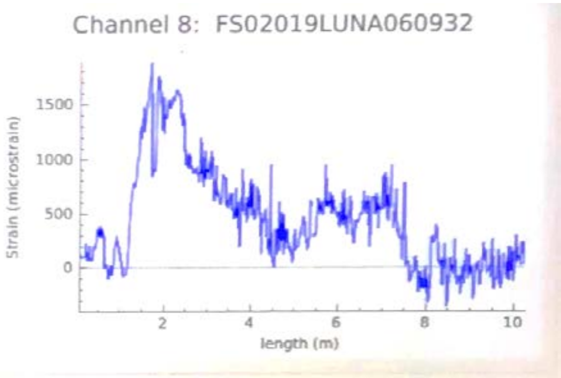


Electrical Resistivity Tomography (ERT) and Fiber Optics

ERT: <u>Measure voltage from applied current at every electrode pair</u>
- Multiple AC frequencies (1-10 Hz)
- Electrodes grouted into boreholes
- Data will inform <u>evolution of brine content</u> (i.e., dry-out)



Fiber-optic distributed sensing
- Scattering in grouted fiber-optics
- <u>Measure temperature and strain</u>
  - Sub-mm resolution in space
  - 1 Hz resolution in time



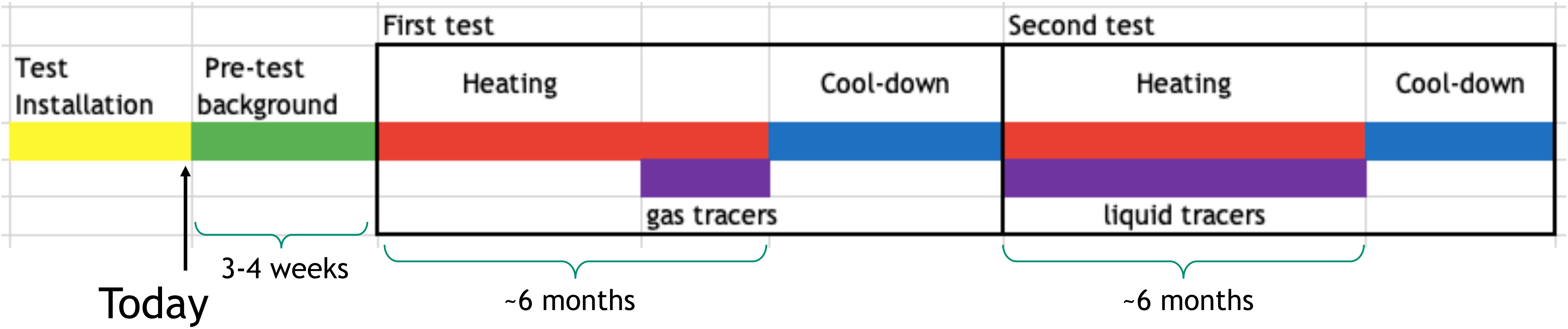
Test Status

Boreholes drilled (Feb-Apr 2019)

Installed instrumentation (May-Aug 2019)

Power turned on in drift Aug 2019

Plumbed and wired experiment (Sept-Oct 2019)



Cementitious Seals

Emplace Pre-fabricated Cement Plug

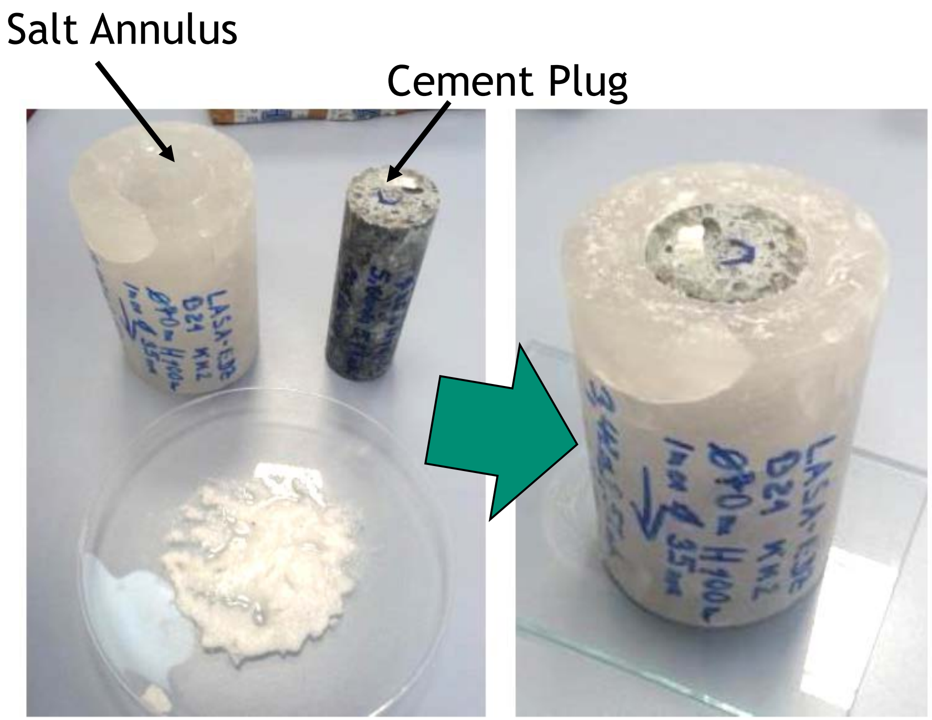
- Snug fit into satellite borehole
- Monitor seal evolution as borehole closes
- Strain gages inside plugs
- Upscale GRS Lab Seals Tests

Overcore Post-test to Analyze Interfaces

Compare:

- Sorel cement (MgO) and salt concrete plugs
- Heated and unheated conditions

<u>Observe salt / brine / cement interactions</u>



Czaikowski & Wieczorek (2016)

Summary and Looking Forward

Not the first heater test in salt or at WIPP

Focus of test is brine availability

- Distribution of different types of brine
- How does damage control brine migration
- Can we predict amount and fate of brine

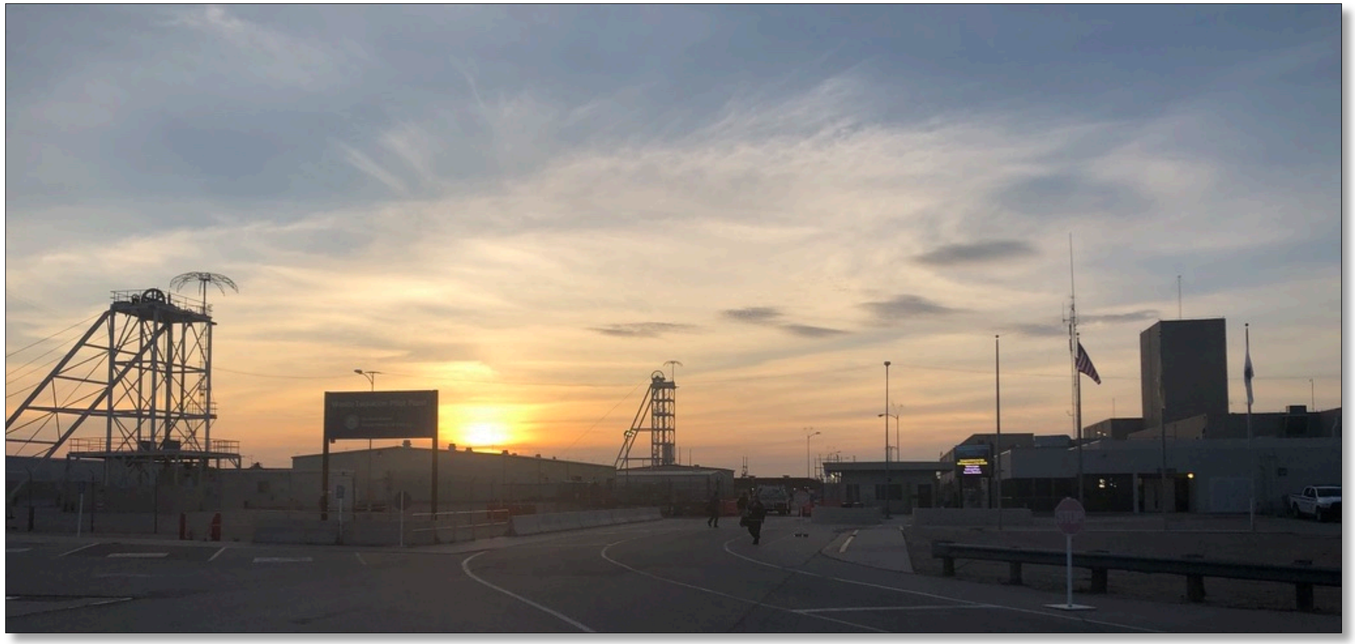
Use new:

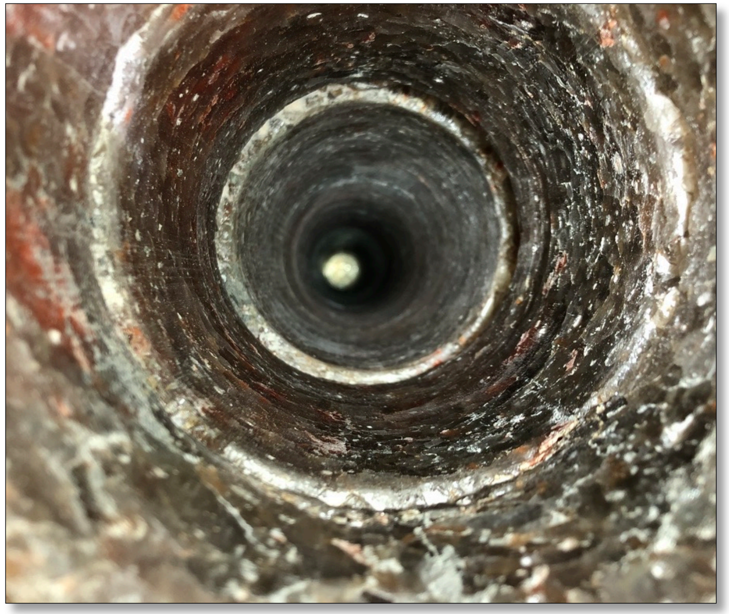
- Geophysical methods (ERT, AE, fiber)
- High-frequency in-drift analytical methods (CRDS, QMS)

New generation of repository scientists underground

Advance generic salt science for heat-generating waste

Thank you!





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