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SAND2015-7408C

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Shear Strength and Deformation along Discontinuities in Salt

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Verantwortung für Generationen / Responsibility for Generations DBE TECHNOLOGY GmbH

PTKA Project Management Agency Karlsruhe, Karlsruhe Institute of Technology

6th US/German Workshop on Salt Repository Research, Design, and Operation

Hotel Pullman Dresden Newa

September 7-9, 2015

Federal Ministry for Economic Affairs and Energy

NNSA National Nuclear Security Administration

U.S. DEPARTMENT OF ENERGY

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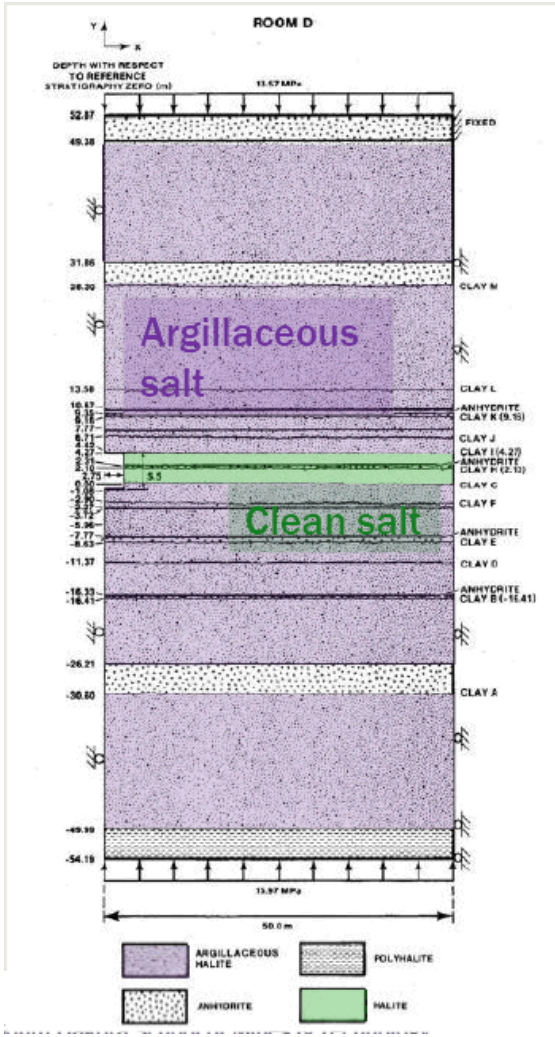
Outline

- Desire to understand shear strength, deformation along salt discontinuities, effects on salt creep, permeability along interface, potential for cracking
- Early tests proposed for WIPP
- Study of oil/NG/potash interaction in SE New Mexico
- Pressurized slot test at Yucca Mountain
- Proposed slot test in salt to create shear along discontinuity, measure displacement, aperture changes
- Other options for shear testing

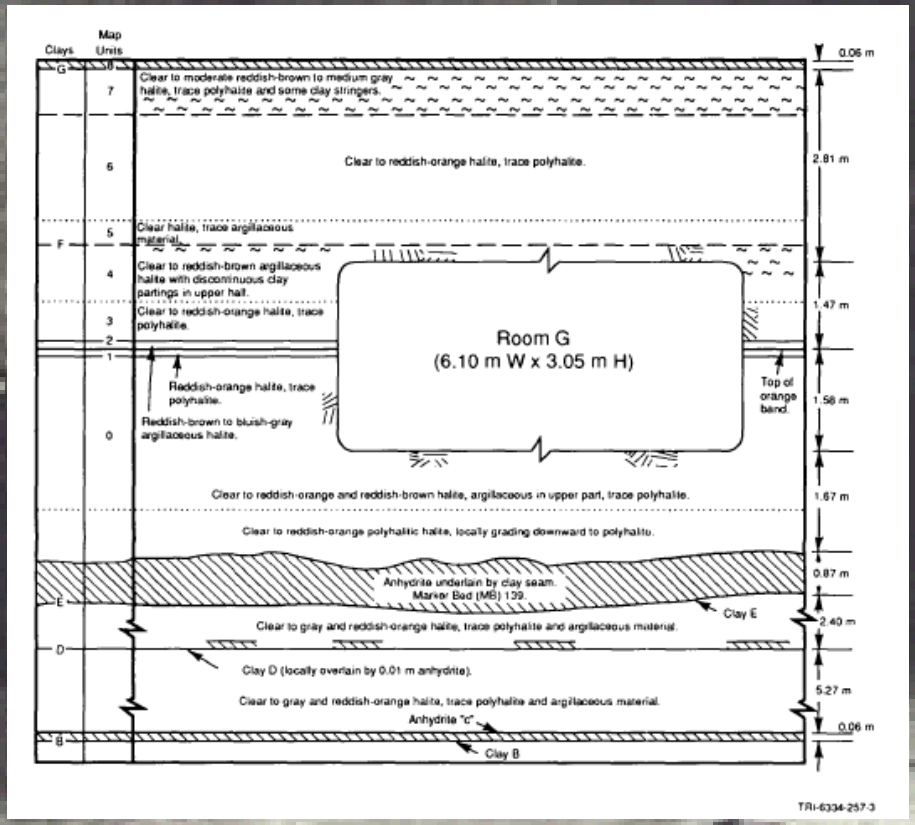
Discontinuities in salt

- Influence of nonhomogeneities in repository performance identified as 1 or 4 key subject areas
- Examples include bedding interfaces, boundary shear planes, joints, and seams of non-halite material such as anhydrite
- Does shear strain cause formation of permeable flow path along an interface, or premature salt failure due to exceeding interface shear strength?
- Little existing in situ data to characterize shear strength of salt interface, resulting effects of shear on interface displacement and permeability

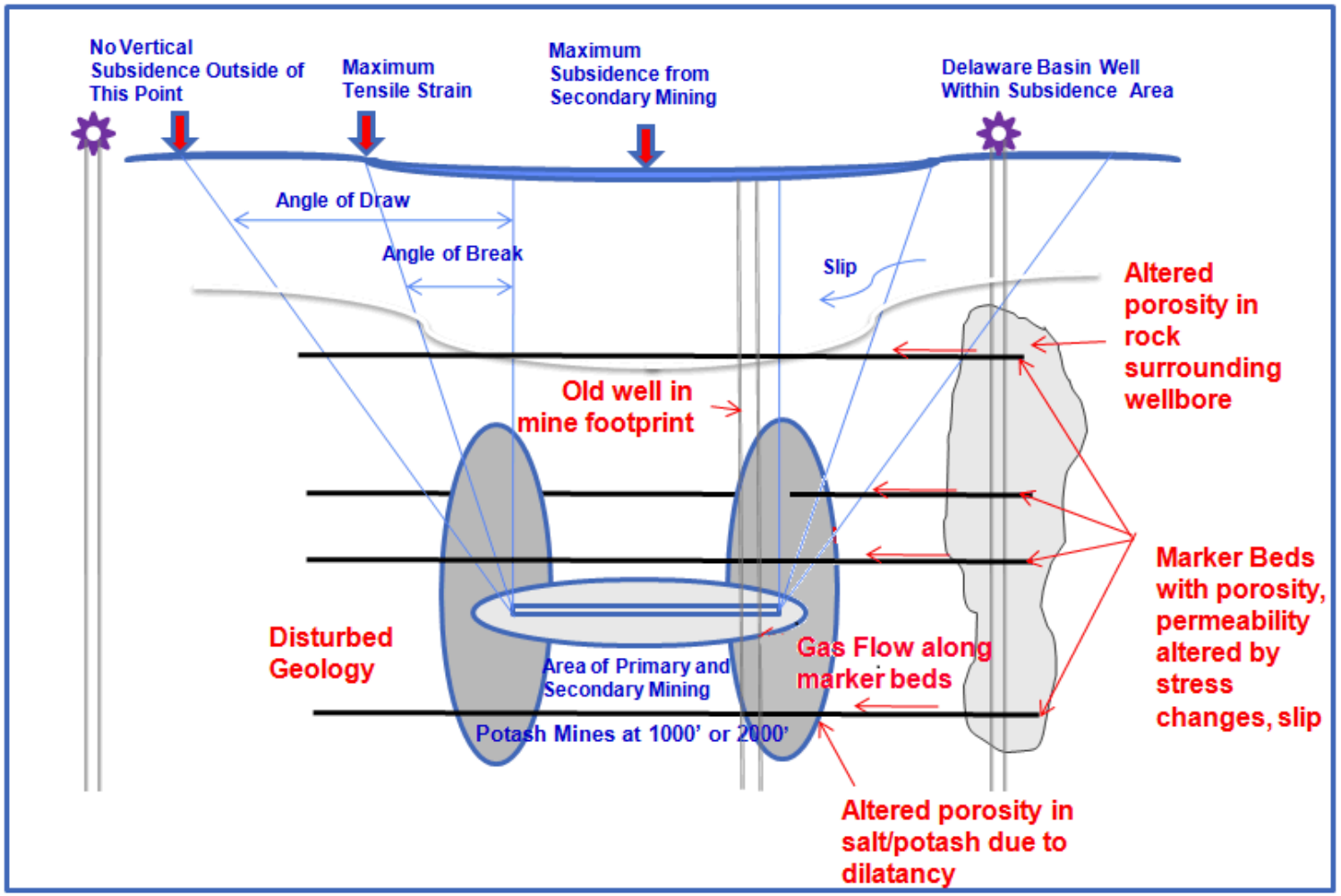


Early test proposed for WIPP

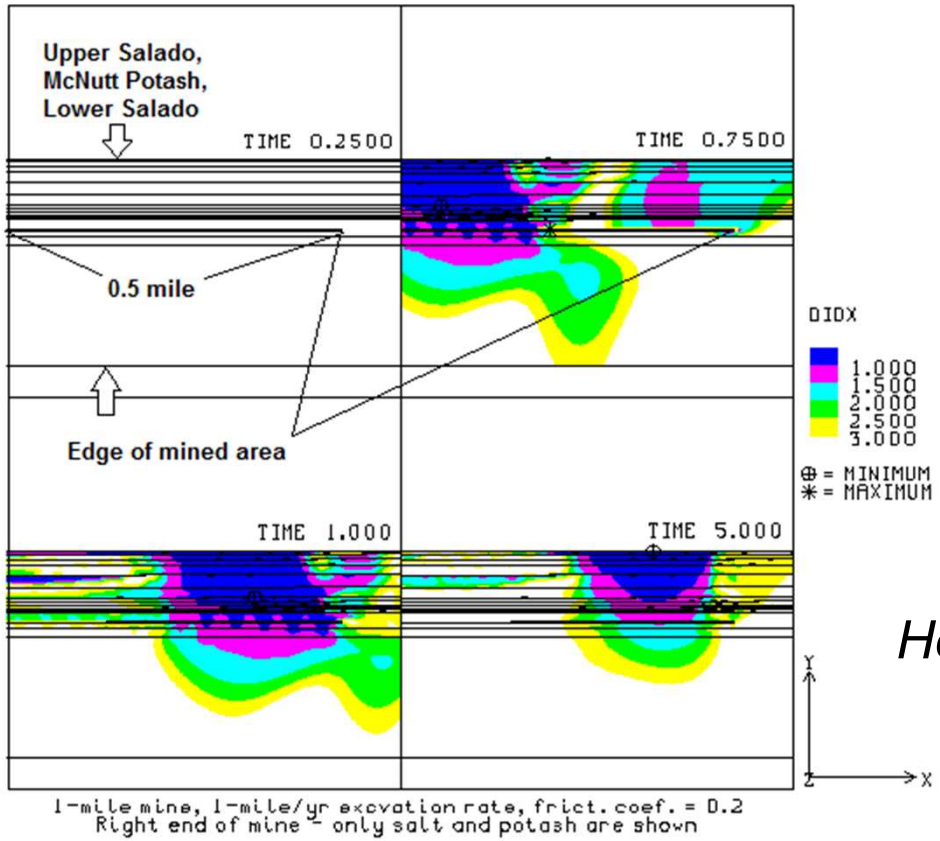
- Munson & Matalucci (1983) proposed in situ test with direct shear across clay seam.
- 1 X 1-m block in wall containing representative clay seam would be isolated by cutting around it in place in one of the drifts.
- Flatjacks installed in slots cut around the block to apply shear and normal stresses.
- Displacements along and across the seam would be measured as function of applied stress.
- **This proposed test never occurred.**

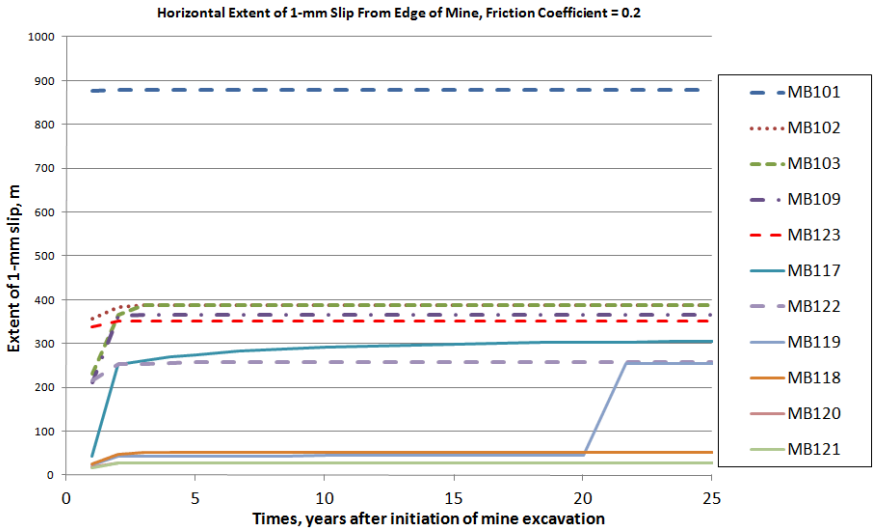


Sandia investigation of interaction of oil, natural gas, potash operations



Damage, slip from interaction



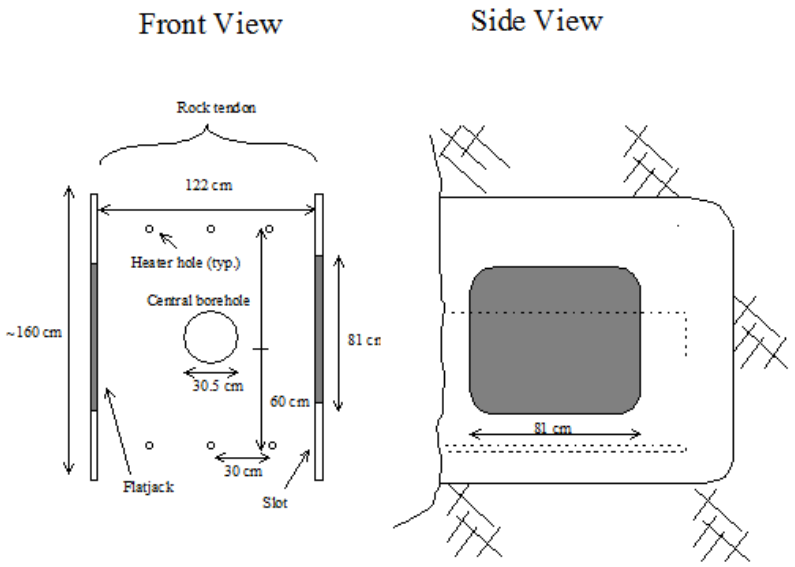


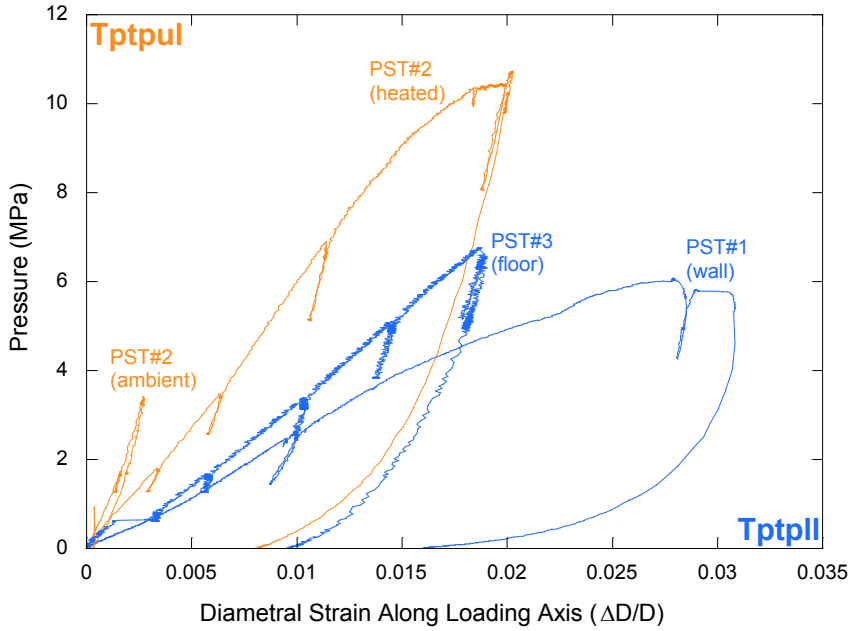
Horizontal extent of 1-mm slip from edge of the mine, friction coefficient=0.2.

Dilatant damage factor for mine 302 m deep, 1 mile/year excavation rate, marker bed friction coefficient = 0.2; factor<1 indicates dilatant damage.

Pressurized slot test at Yucca Mountain, Nevada

- Four pressurized slot tests performed May-December 2002 in volcanic tuff, during the characterization of Yucca Mountain as a potential radioactive waste repository
- Designed to measure a rock mass modulus and to determine the extent of nonelastic, permanent deformation under high stress loading conditions
- Tests performed with flatjack pressures 6-10 MPa (in situ σ_v=4.3 MPa)
- Tests #1, #3 ambient temperature; Test #2 performed at both ambient and heated (90C) conditions

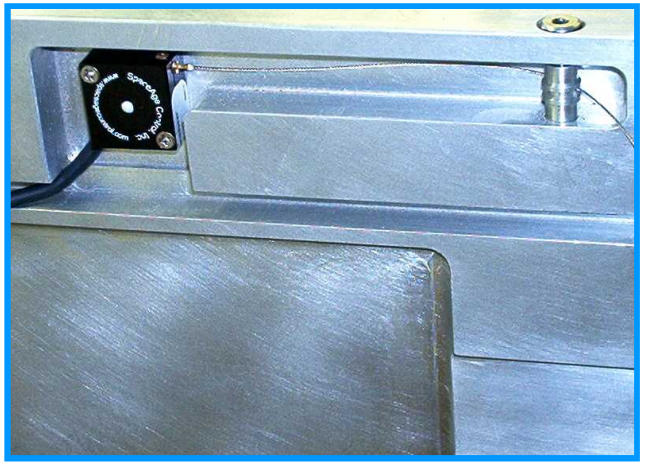




PST Test Procedure

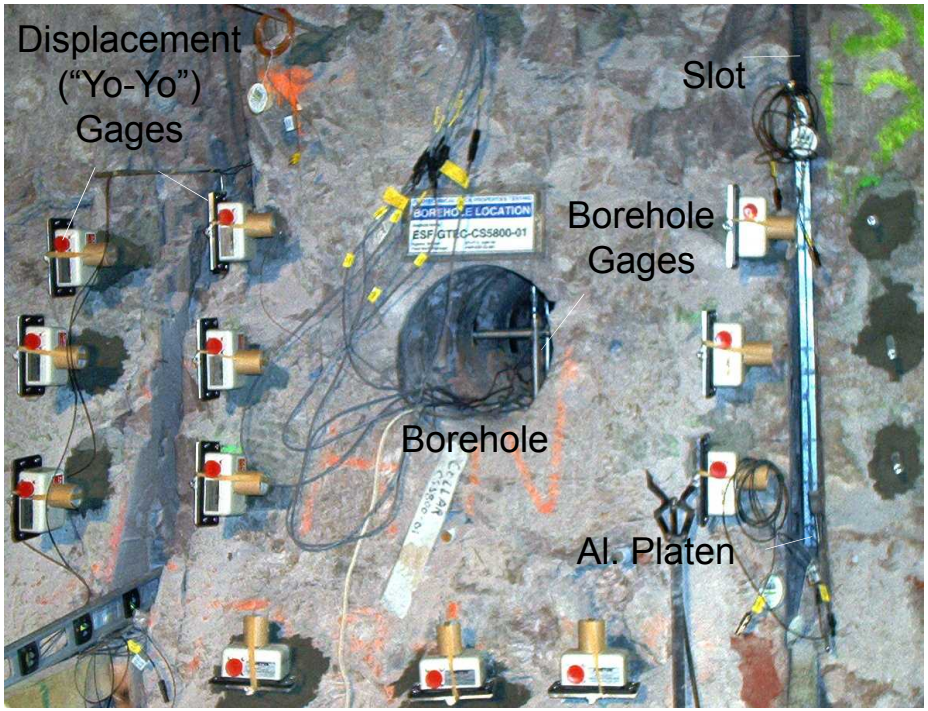
- Site preparation
  - Drill dowel pin holes
  - Mount surface deformation pins
  - Core the central hole and map locations of prominent lithophysae
  - Instrument central hole
- Slot cutting and flat-jack installation
  - Cut slots with Hydraulic Rock Saw
  - Map surface of slots
  - Install flat-jacks and platens along with displacement gages
  - Install instrumentation for remotely measuring pin deformations
- Slot pressurization
  - Pressurize flat-jacks, and increase until null slot displacement is achieved.
  - Cycle flat-jack pressures.
  - Maintain constant pressure in flat-jacks to check the time dependent deformation of the rock mass

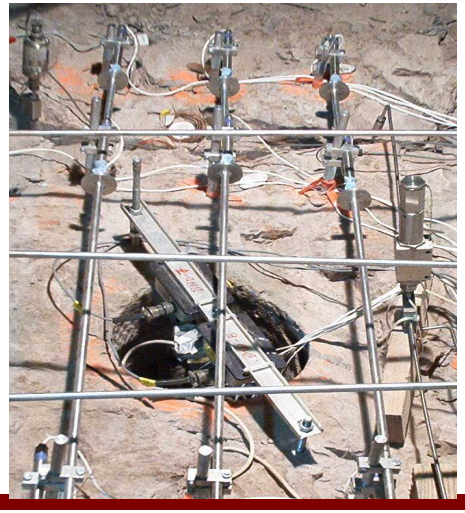
Instrumented Flat-jack



Rotating linear potentiometers gages
(4 per flat-jack, 0-5 cm range)
measure displacements between the two load bearing platens.

PST Instrumentation



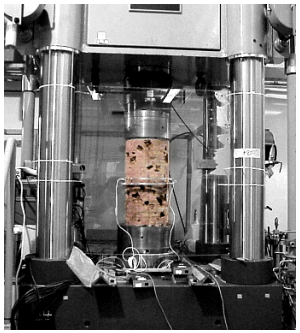


- Total data and video channels recorded 35 (typical):
  - –12 surface displacement gages (9 horizontal + 3 vertical)
  - –6 borehole displacement gages (3 horizontal + 3 vertical)
  - –2 video channels (1 axial + 1 borehole crown)
  - –8 platen displacement gages (4 left + 4 right)
  - –2 pressure transducers in parallel (1 left + 1 right flat-jacks)
  - –5 thermocouples (2 flat-jacks + 1 rib + 1 ambient air + 1 borehole)
- Data from borehole displacement gages were excellent and provided the basis to determine in situ mechanical properties of lithophysal tuff.

Comparison of E and Strength

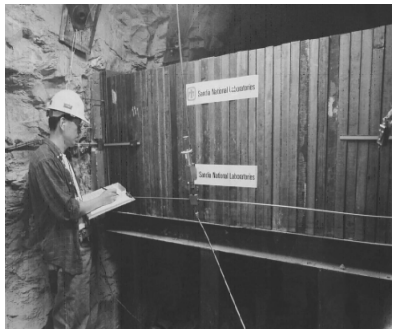
Test	Location	Condition	Tuff Unit	E (GPa)	Strength (MPa)
11.5” diameter core	ESF	Saturated,24°C	Tptpul (3)	5.9 ± 0.9	11.2 ± 1.7
11.5” diameter core	ECRB	Saturated,24°C	Tptpll (1)	5.3	15.7
11.5” diameter core	ESF	Room dry,24°C	Tptpul (7)	13.7 ± 5.3	22.2 ± 6.9
11.5” diameter core	ECRB	Room dry,24°C	Tptpll (3)	7.6 ± 2.3	21.2 ± 7.7
11.5” diameter core	ESF	Dry, 190-200°C	Tptpul (3)	10.3 ± 3.2	30.5 ± 9.5
11.5” diameter core	ECRB	Dry, 190-200°C	TPtpll (2)	6.8 ± 0.4	31.7 ± 0.8
Goodman Jack	TTF	Ambient / Heated	Tptpmn	3.3 / 5.9	NA
Plate Loading Test	TTF	Ambient	Tptpmn	17	NA
Plate Loading Test	TTF	43°C	Tptpmn	43	NA
PST#1	ESF	Ambient	Tptpll	0.5 ± 0.3	6*
PST#2	ESF	Ambient	Tptpul	3.0 ± 0.5	NA
PST#2	ESF	Heated, >80°C	Tptpul	1.5 ± 0.5	11*
PST#3	ECRB	Ambient	Tptpll	1.0 ± 0.3	7*

*-Peak Pressure in the Flat-Jack



Lab. Core

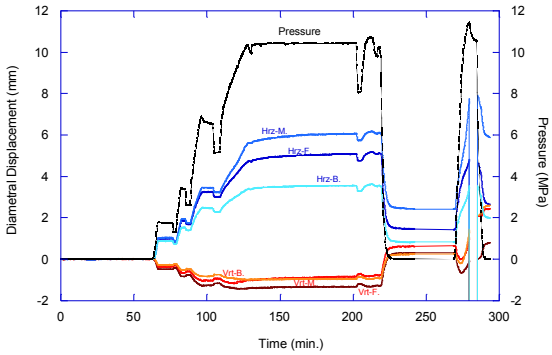
Goodman Jack



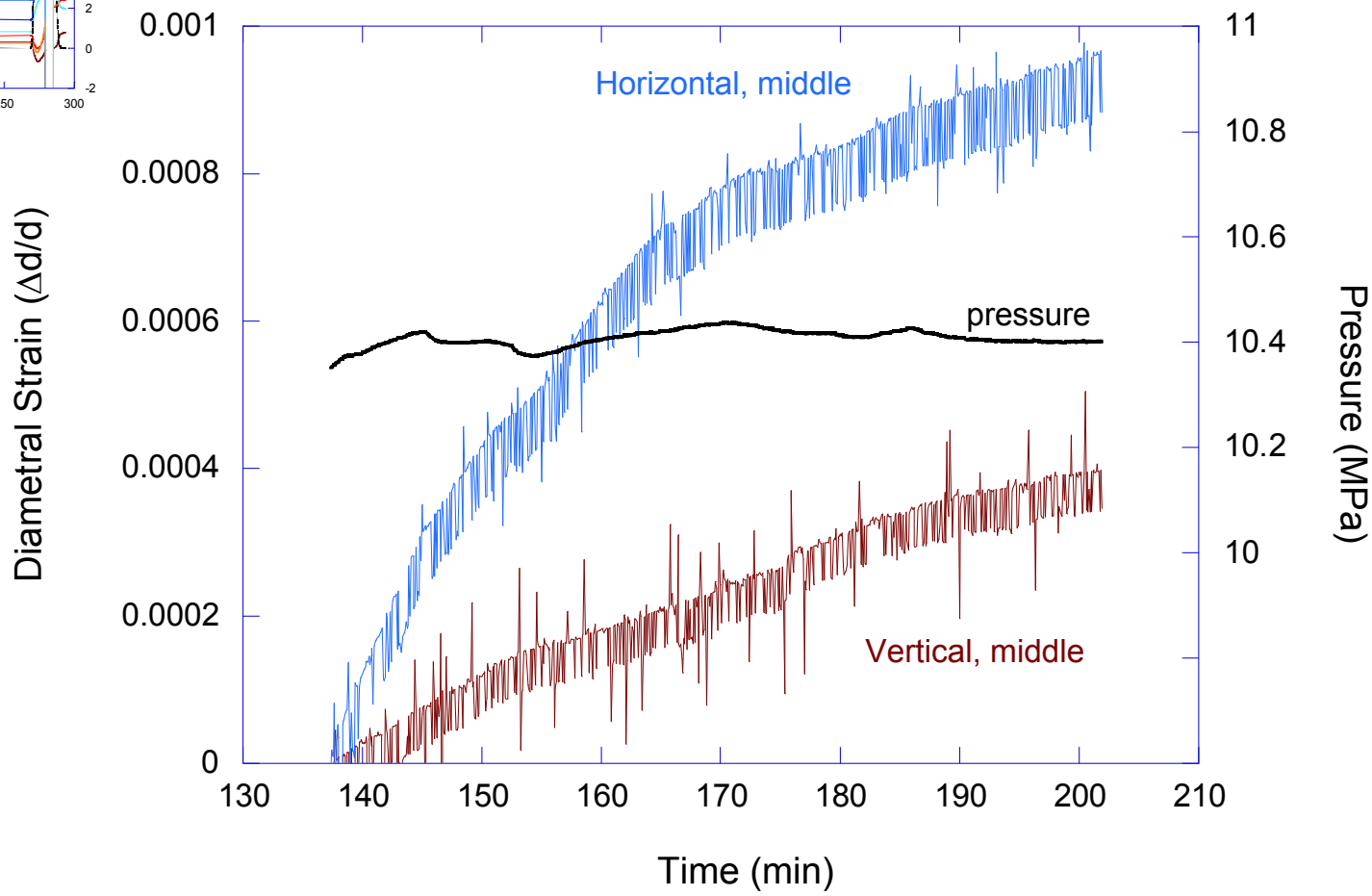
PLT

PST

“Creep” behavior in fractured tuff (PST#2)

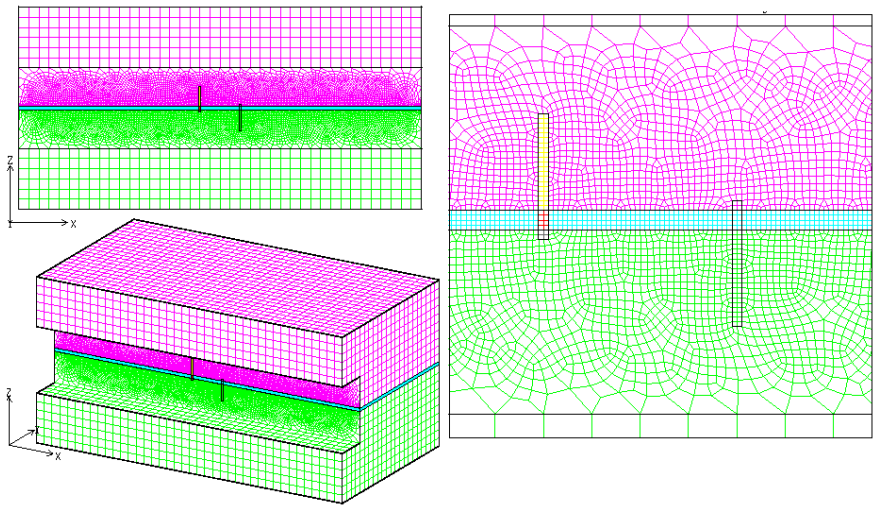


Not actually creep behavior, but inelastic behavior due to compression of lithophysae, existing fractures



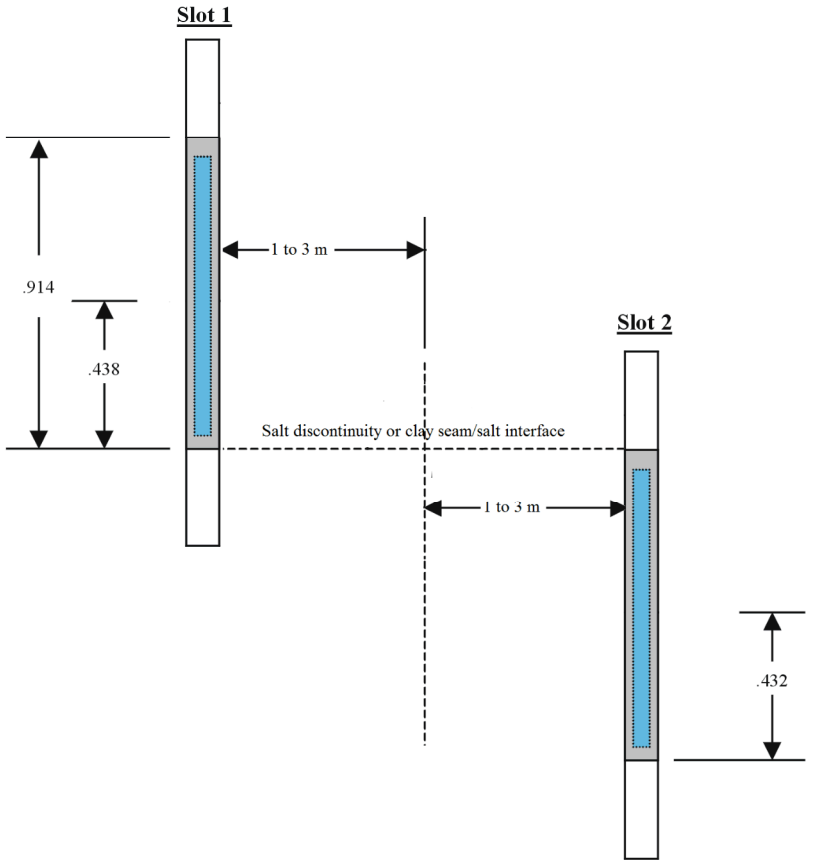
Proposed slot test in salt

- Measurements of applied pressure and displacement will capture the evolution of shear-induced characteristics of the inhomogeneity and neighboring salt during the test.
- Changes in permeability may be approximated by measurement of the changes to the interface aperture.
- Pre-test analyses to predict changes to interface



Platen Dimensions & Installation Locations
for Left Slot 1/A & Right Slot 2/B
(All dimensions in meters unless noted otherwise)

1. Platen assembly size = .914 x .914 (nominal width of 3.80 cm)
2. Flatjack size centered inside platens = .813 x .813
3. Slot width varied from 3.90 cm to 4.445 cm



Pre-test analyses, compare to data

- Seam/interface may be modeled as contact surface, or as thin layer or one of more materials
- Select material models, parameters for shear stiffness & strength, change in permeability
- Compare predictions of displacement along interface, change in aperture thickness, based on design, actual pressure application to measured values
- Also consider including long-duration constant pressure, to collect measurements for transient, steady-state creep parameters
- Measure permeability or flow in interface (and changes during test), if feasible
- Ambient test required; additional heated test should be considered

Other options for in situ shear testing

- **Pressurized borehole test:** Similar to pressurized slot test, but instead drill 10-cm boreholes that can be sealed and pressurized up to 10 MPa
- **Hydraulic fracture borehole test:** Similar to pressurized borehole, hydrofrac holes, inject dye to detect flow through seam (similar test proposed for WIPP)

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Thank you for your attention!