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Novel Experimental Techniques to Investigate Wellbore Damage Mechanisms

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Sandia National Laboratories

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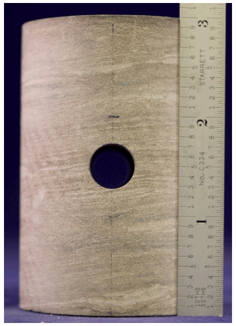
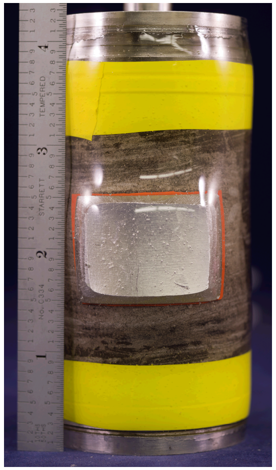
In Situ Stress States

- In situ stress state vital for subsurface engineering projects, hazard predictions
- Few measurement techniques
  - Flatjacks, overcoring, anelastic strain recover, borehole methods
- Borehole methods
  - Integrate density logs for vertical stress
  - Leak off tests for minimum horizontal stress
  - Maximum horizontal stress must be calculated from borehole breakouts
- Borehole breakouts
  - Diametrically opposed shear/compressive/buckling fractures resulting from stress concentration at borehole
  - Measure width using imaging logs, calculate maximum horizontal stress assuming failure envelope, rock properties
- DOE Jason 2014 Report – errors in stress measurement can be as high as 30-40% in complicated terranes

Laboratory Wellbore Simulations

- True Triaxial Systems
  - Recreate in situ stress state
  - Expensive, niche equipment
- Hollow cylinders
  - Common equipment
  - No differential stress
- Sandia WEllbore SImulation (SWESI)
  - Utilizes standard equipment
  - Recreates in situ stress state
  - Kirsch's hole in a plate





SWESI Geometry

- 50 mm diameter sample, 75 mm long
  - 11.3 mm hole perpendicular to axis
- Borehole cover
  - Solid
  - Tapped for pore fluid
- Silicone rubber pad
- UV cure polyurethane

Experimental Methodology

Mancos Shale

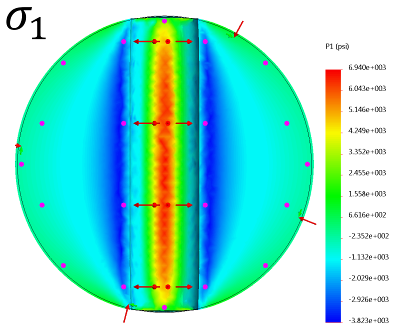
- Finely laminated Cretaceous mudrock
- Cores prepared 3 orientations
  - Parallel, perpendicular, 45 degrees
- 3 different confining pressures
  - 6.89, 13.79, and 20.68 MPa
- 1.6 x 10^{-5} sec^{-1} strain rate

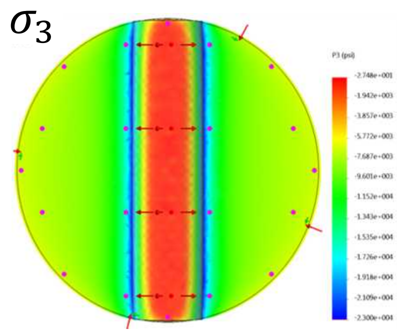
Sierra White Granite

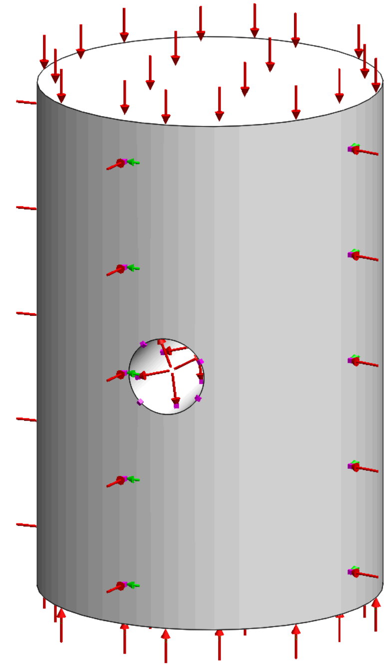
- Granodiorite, 1-3 mm grain size
- 3 different borehole chemistries
  - Dry, DI water, Na/Ca Bicarbonate (pH 9)
- 3 different effective confining pressures
  - 8.6, 17.2, and 34.4 MPa
- 3 x 10^{-6} sec^{-1} strain rate

SWESI Validation

- 3d Elastic modelling
  - Simulate 89 kN axial force, 6.89 MPa confining pressure
  - Stresses distributed evenly along wellbore
- Deformation results in breakouts
  - Shear fracture bounded breakout
  - Distributed evenly along wellbore







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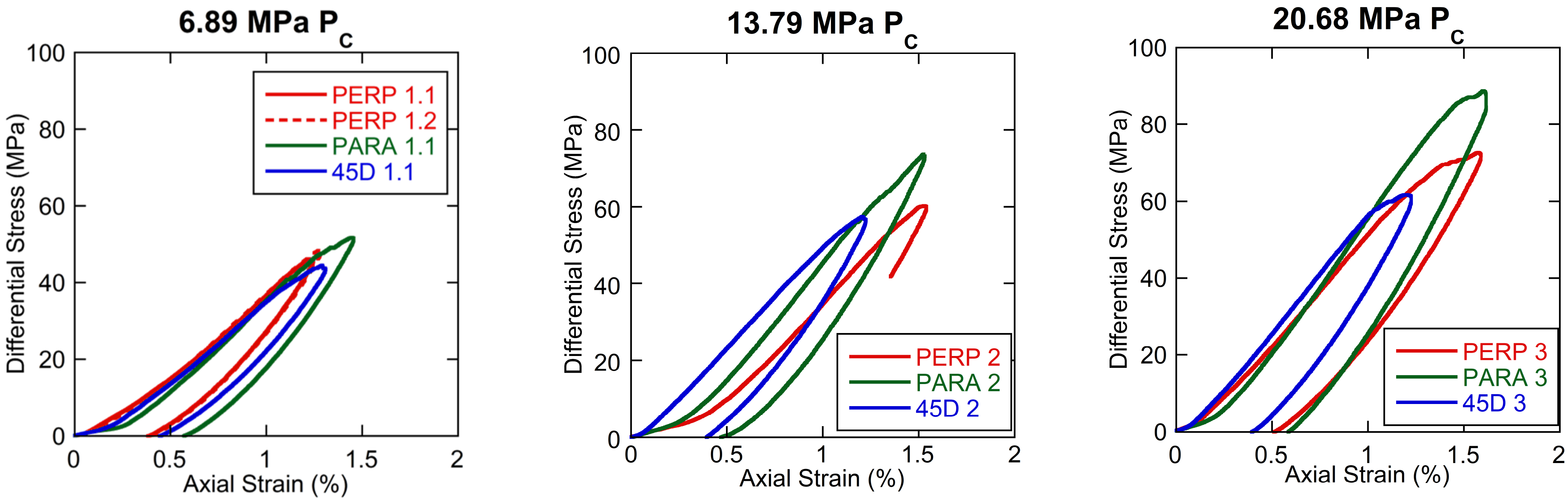
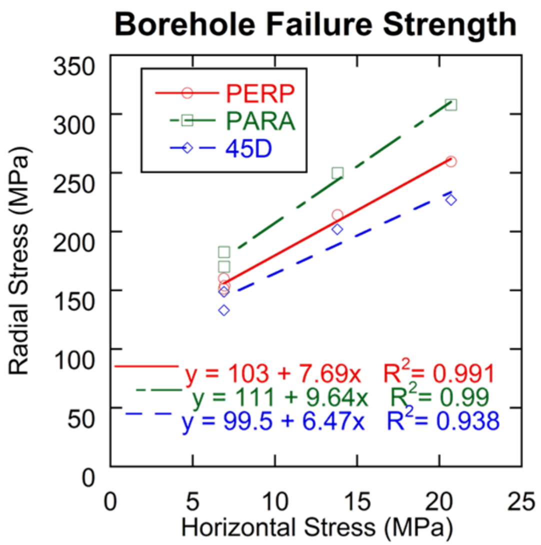
Bedding Effects on Borehole Breakout

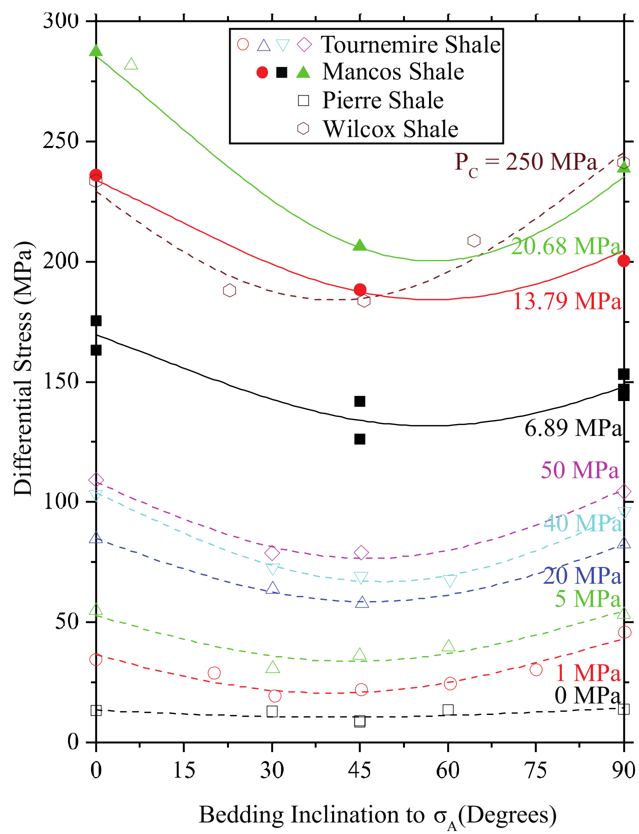


- Bedding orientation affects failure strength
  - Parallel stronger than perpendicular, stronger than 45 degrees
- Failure strength increases with increasing confining pressure
- Bedding orientation affects sample stiffness
  - Parallel stronger than perpendicular, stronger than 45 degrees

Bedding Effects on Failure Strength

- Borehole strength from Kirsch's solution
  - $\sigma_{Borehole} = 3 * \sigma_{Axial} - P_C$
- Borehole strength increases with increasing P_C
  - Parallel > Perpendicular > 45 Degrees
- Borehole strength fit with *Donath*, 1972 failure envelope
  - $\sigma_D = A - B\cos 2(C - \theta)$
  - A, B, C constants
  - θ inclination of bedding to axial stress
- Borehole strength higher than failure strength
- Minimum angle higher for borehole
- Larger stress variation for P_C
  - Increases with increasing P_C

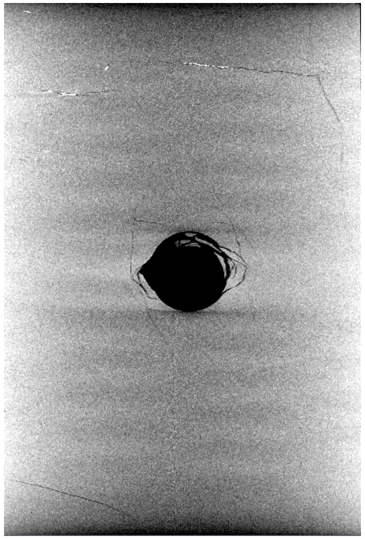


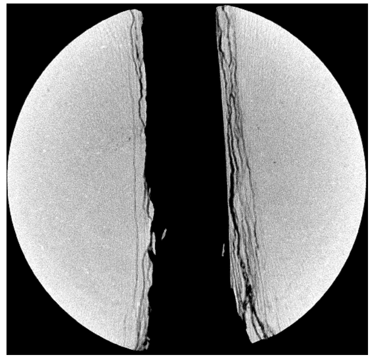


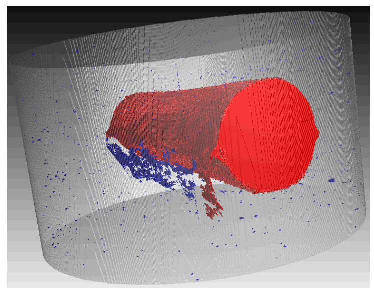
Ibanez & Kronenberg, 1997; *Crook et al.*, 2002; *Niandou et al.*, 1997

Breakout Geometry

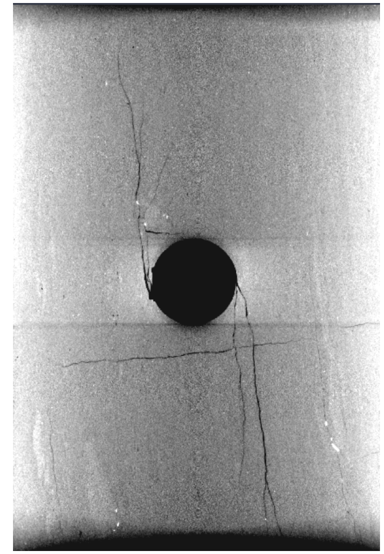
Perpendicular

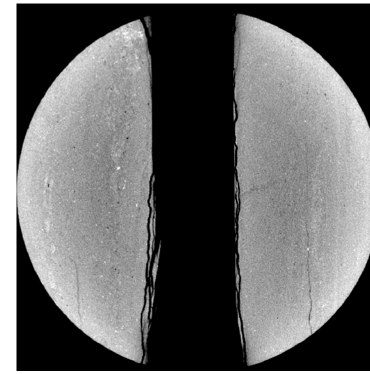




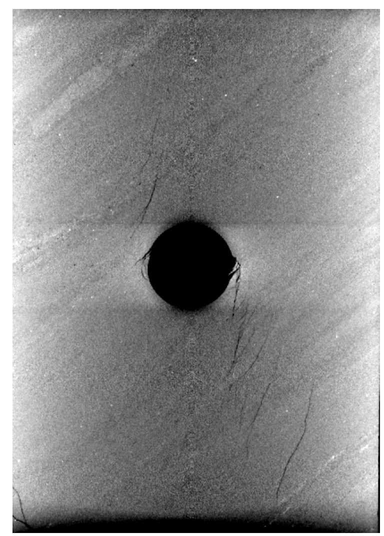


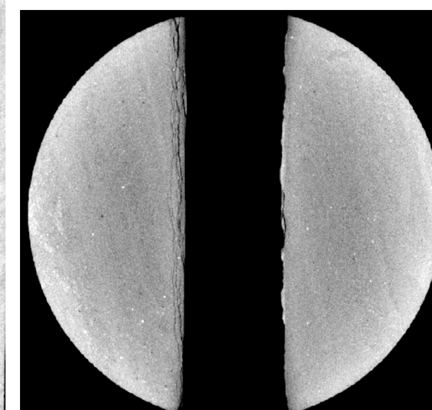
Parallel





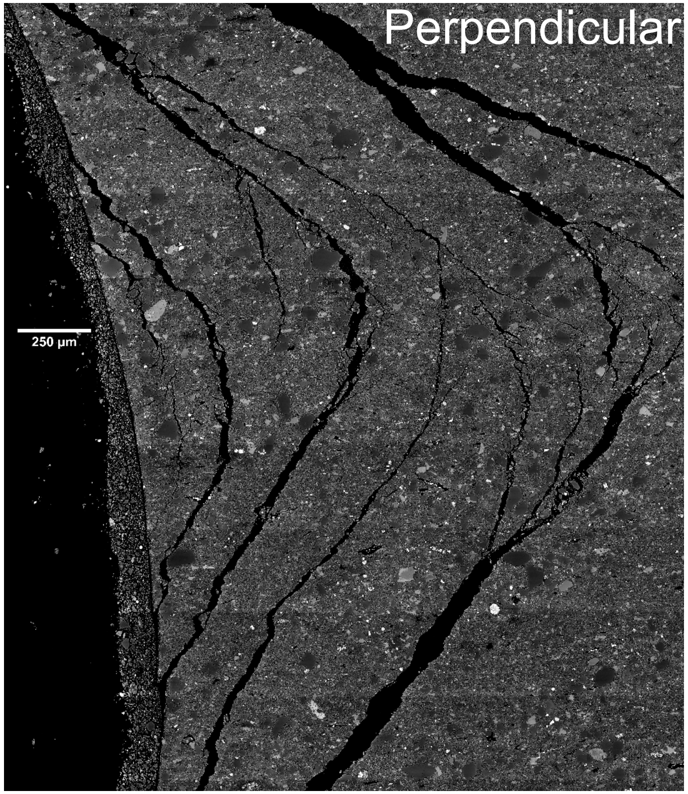
45 Degrees

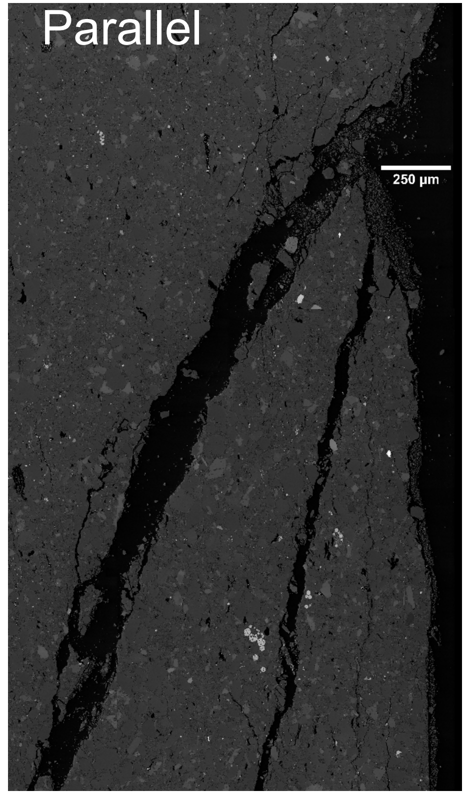


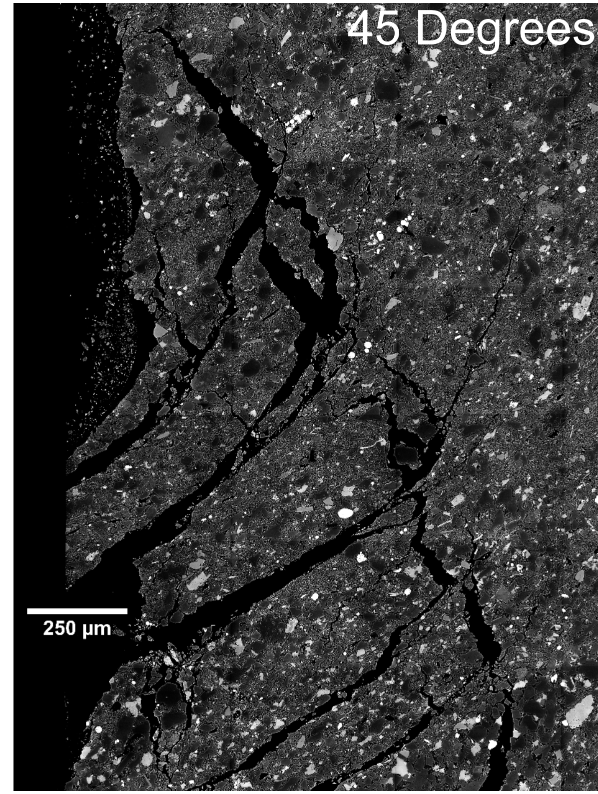


- Perpendicular - dog eared shape; breakouts grow larger
- Parallel - Vertical fractures; no breakout; forms at bottom
- 45 Degrees - Dog ear shape; En echelon fractures

Breakout Microstructures







Perpendicular

- Rounded nose
- Branching, horsetail tips

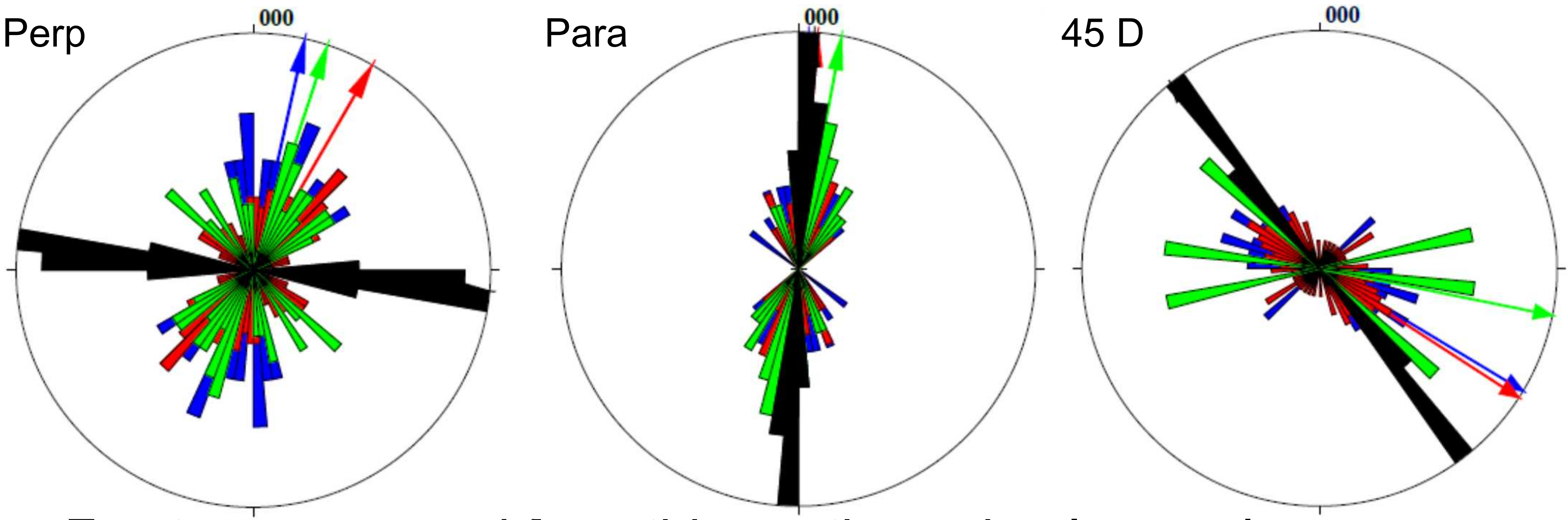
Parallel

- Long vertical fractures
- Fractures don't intersect

45 Degrees

- En echelon progression
- Fracture along bedding

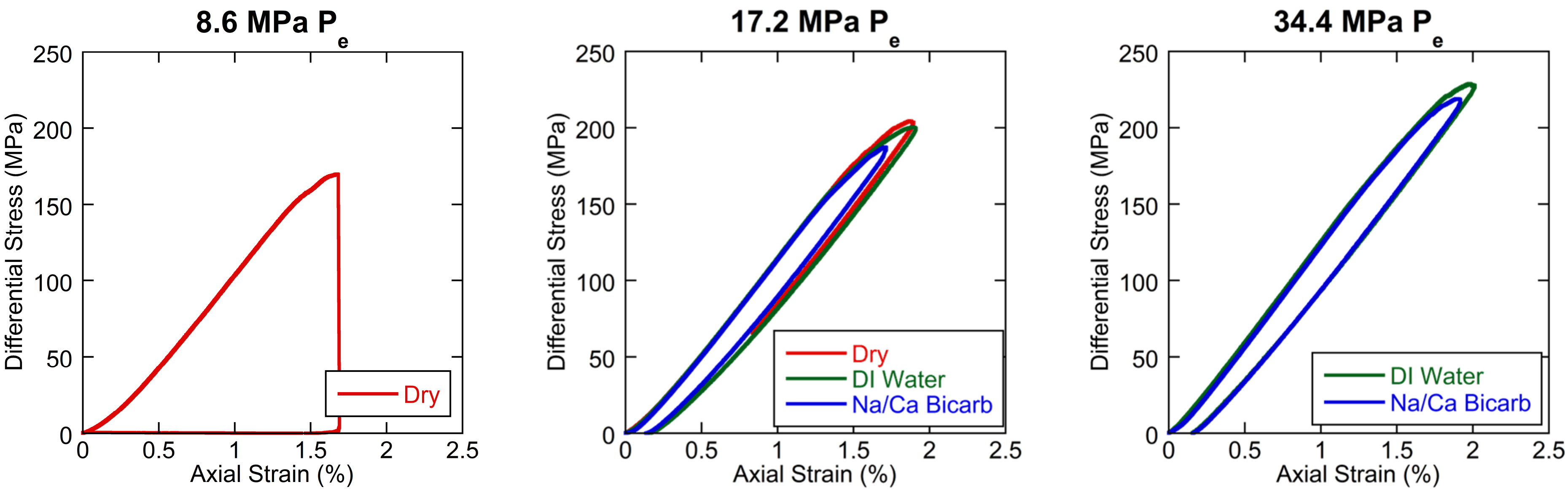
Bedding Effects on Fracture Orientation



- Fracture measured from thin section using Image J
  - Layering based on grey value
- Perpendicular – Steeper dip in clastic layers than clay rich layers
- Parallel – Highest dips, follows bedding dip
- 45 Degrees – shallowest dips, subparallel to bedding

Bedding
Light
Dark
Mixed

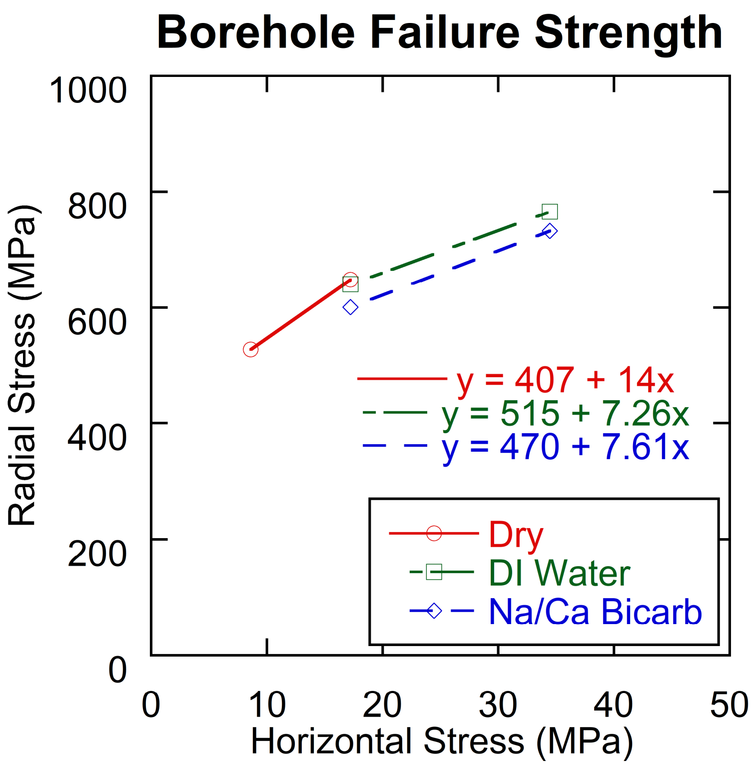
Fluid effects on Borehole Breakout



- Failure strength increases with increasing effective pressure
- Low P_e failure by through going fracture, little breakout
  - Higher pressure tests fail by slight stress drop
- Fluid alters failure strength
  - Na/Ca bicarbonate weaker
- Fluid does not affect stiffness

Fluid effects on Borehole Breakout

- Borehole strength from Kirsch's solution
  - $\sigma_{Borehole} = 3\sigma_{Axial} - P_C$
- Borehole strength increases with increasing P_C
  - Big increase from 8.6 MPa to 17.2 MPa P_C
- Parallel slopes for different fluids
  - Na/Ca bicarbonate shifted to lower strength
  - Room temperature
- Future work
  - Different fluids (acid, mineral oil)
  - Different load paths



Conclusion

- SWESI sample geometry capable of recreating borehole deformation mechanisms
  - Resulting failure consistent with borehole breakout geometries
- Flexibility of geometry and triaxial loading frames allow for wide range of testing conditions
  - Different bedding orientations, fluid chemistries, confining pressures, strain rates
- Bedding orientation has strong influence on borehole breakout
  - Clear variation in failure strength, breakout geometry, fracture orientation
- Fluid chemistry influence failure strength
  - No change for DI water, weakening for basic solutions