SAND2017-11439PE

SPE Phase I Material Properties

Scott Broome

Sandia National Laboratories

Aviva Sussman, Erika Swanson, Jennifer Wilson

Los Alamos National Laboratory

10 October, 2017 State of Analysis

Sandia National Laboratories is a multimission laboratory managed and operated by National Technology and Engineering Solutions of Sandia, LLC., a wholly owned subsidiary of Honeywell International, Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.

Material and Fracture Property Analyses

Linked multi-scale analyses on pre-SPE-1 and post SPE-2, 3 and 5 granite

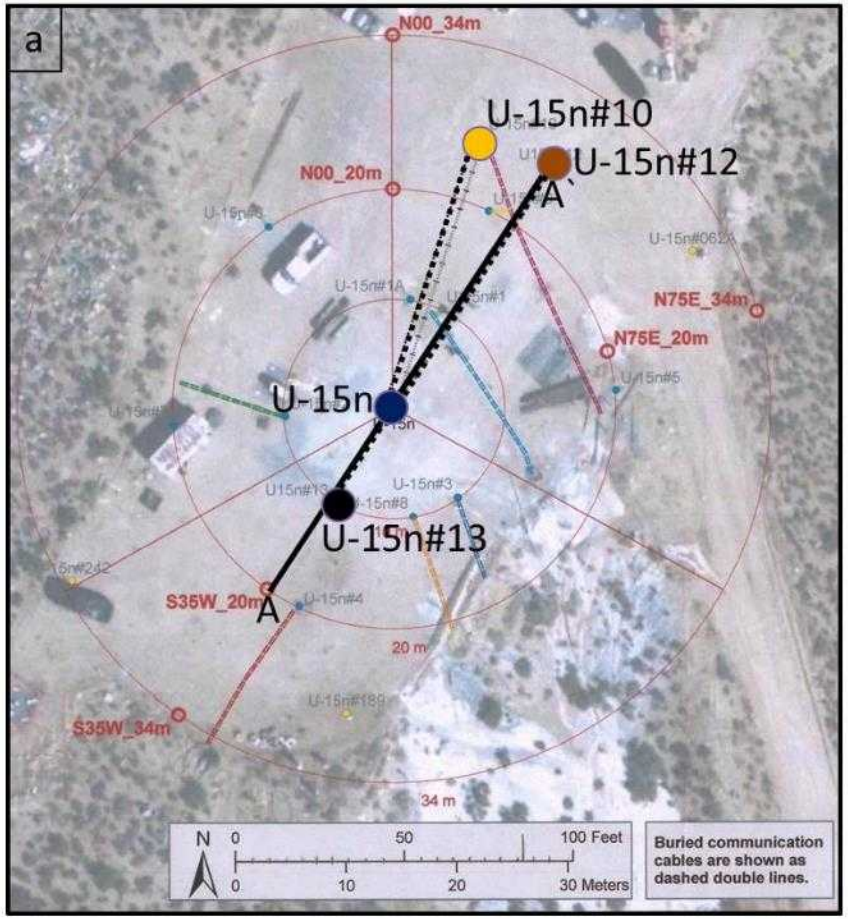
- **Optical Microscopy**
  - defines extent of damage and controls on surface effects
  - provides damage history (tectonic vs explosion)
  - constrains anisotropy

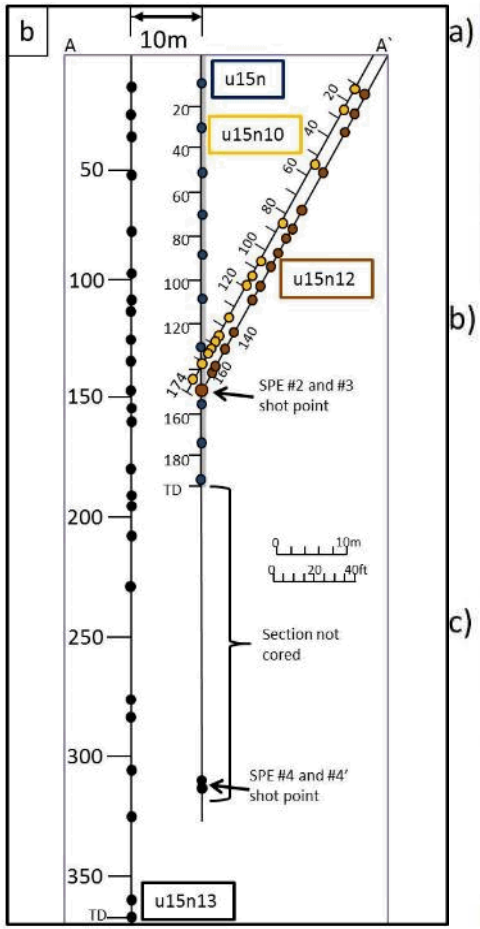
- **Core-scale Material Property Testing**
  - Unconfined and Triaxial compression (Hydrocode model development)
  - Dynamic and Quasi-static Brazilian Disc Tension (Hydrocode model development)
  - Triaxial compression to investigate permeability and damage relationship

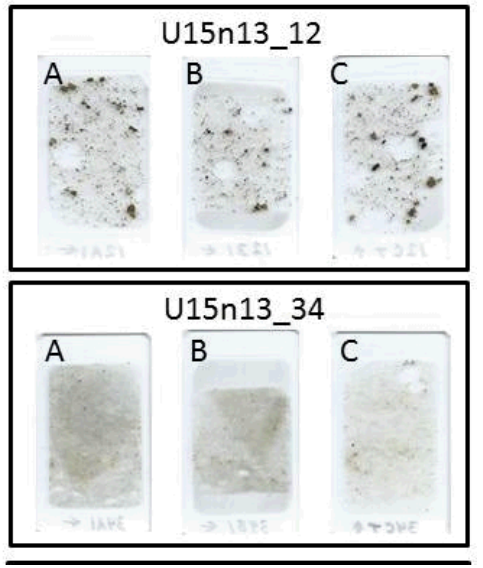
- **Core-scale Fracture Property Testing**
  - Direct Shear tests on natural fractures
  - Triaxial shear on natural fractures (incorporating pore pressure and confining pressure on natural fractures)
  - P&S velocity as a function of fracture aperture with water as coupling medium

Material and Fracture Property Analyses

Linked multi-scale analyses on pre-SPE-1 and post SPE-2, 3 and 5

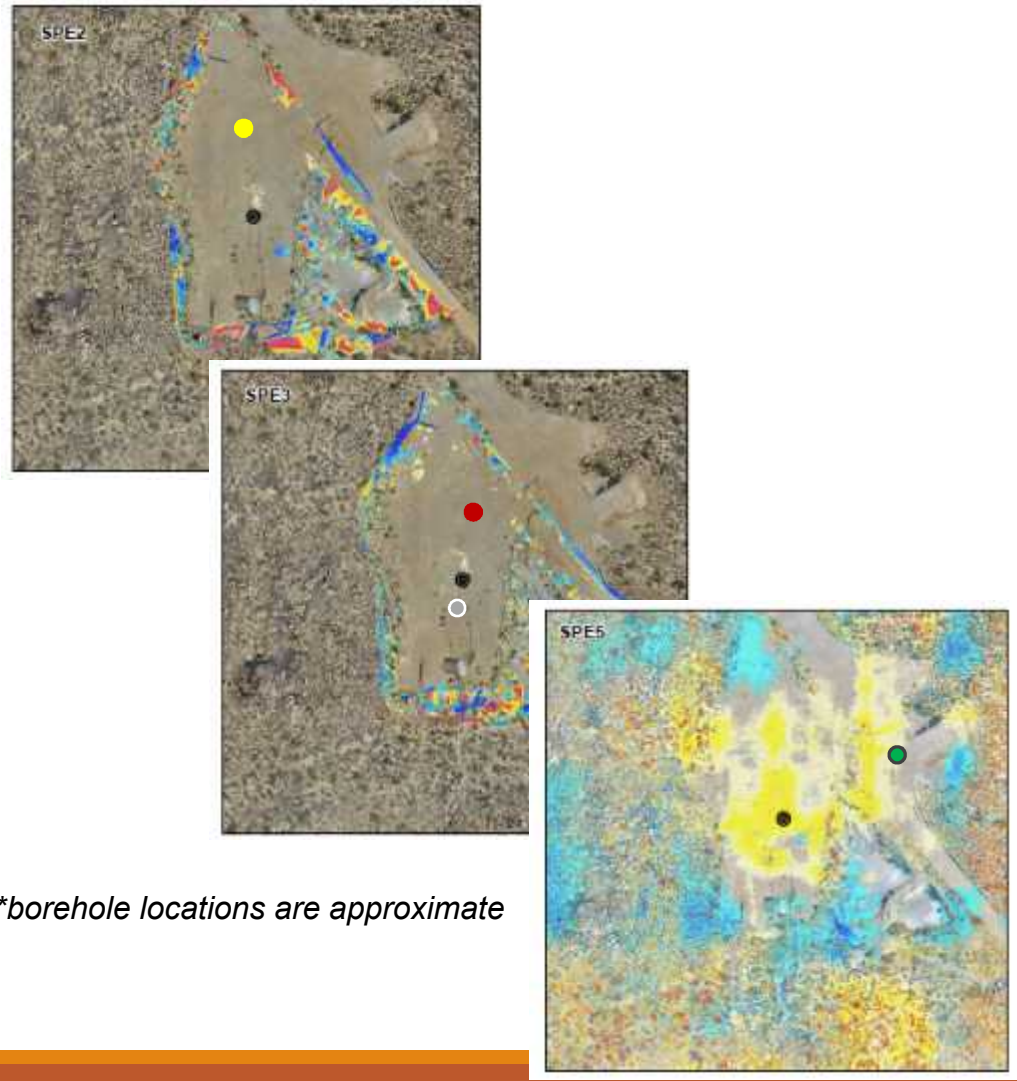




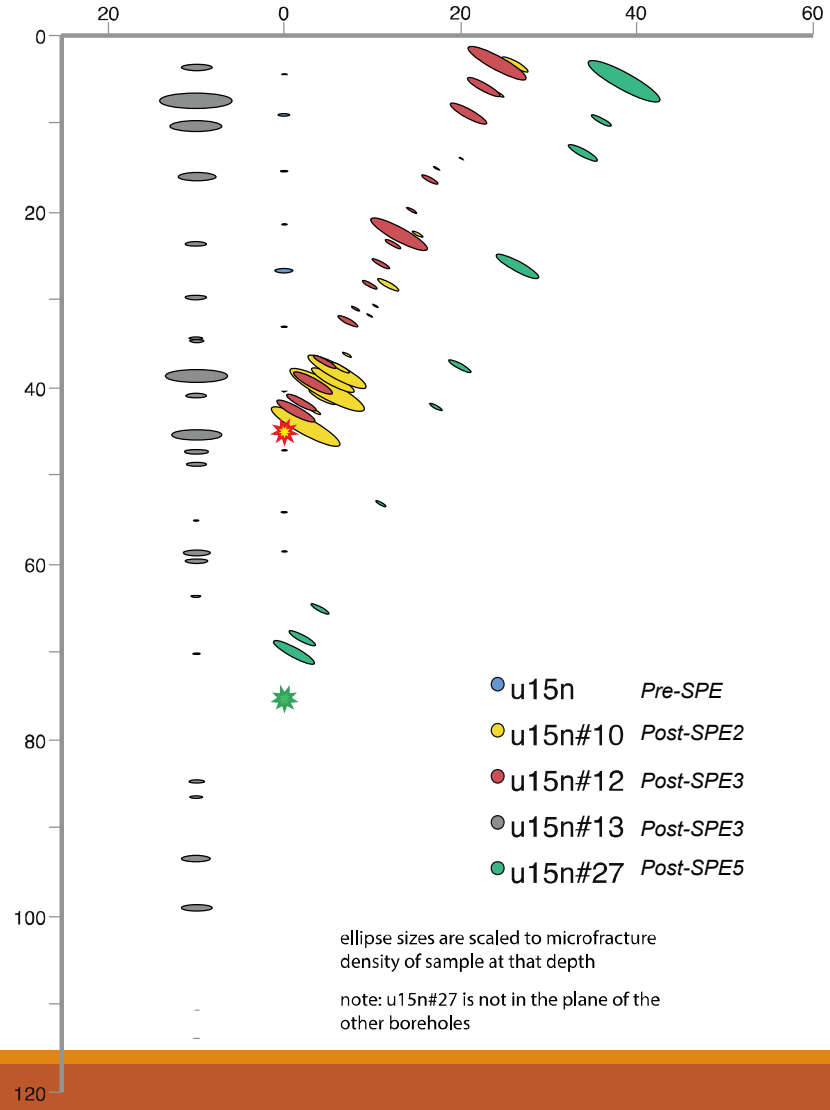


Microscale Material and Fracture Property Analyses

Linked multi-scale analyses on pre-SPE-1 and post SPE-2, 3 and 5 granite demonstrate rock behavior that controls surface effects



**borehole locations are approximate*

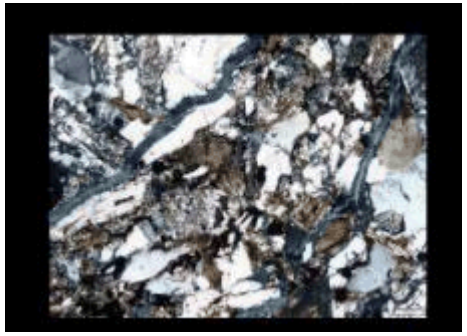


Microscale Material and Fracture Property Analyses

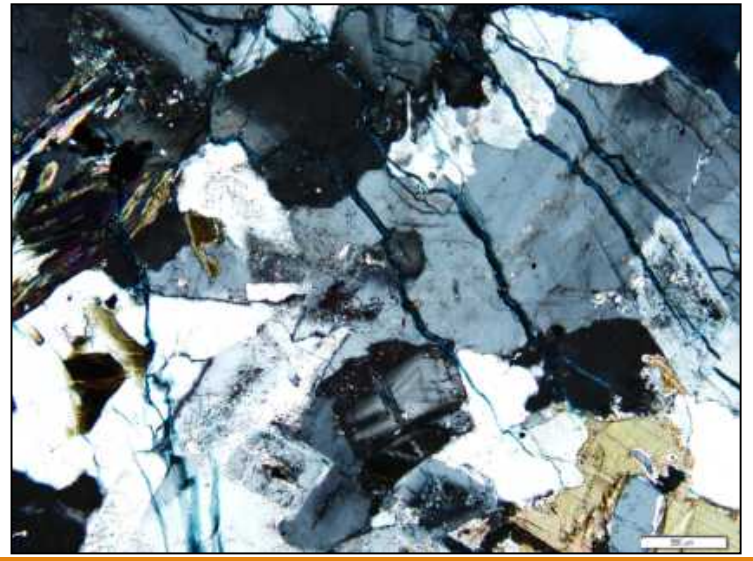
Optical Microscopy: anisotropy and damage history

U15n13
78ft depth
Intact granite

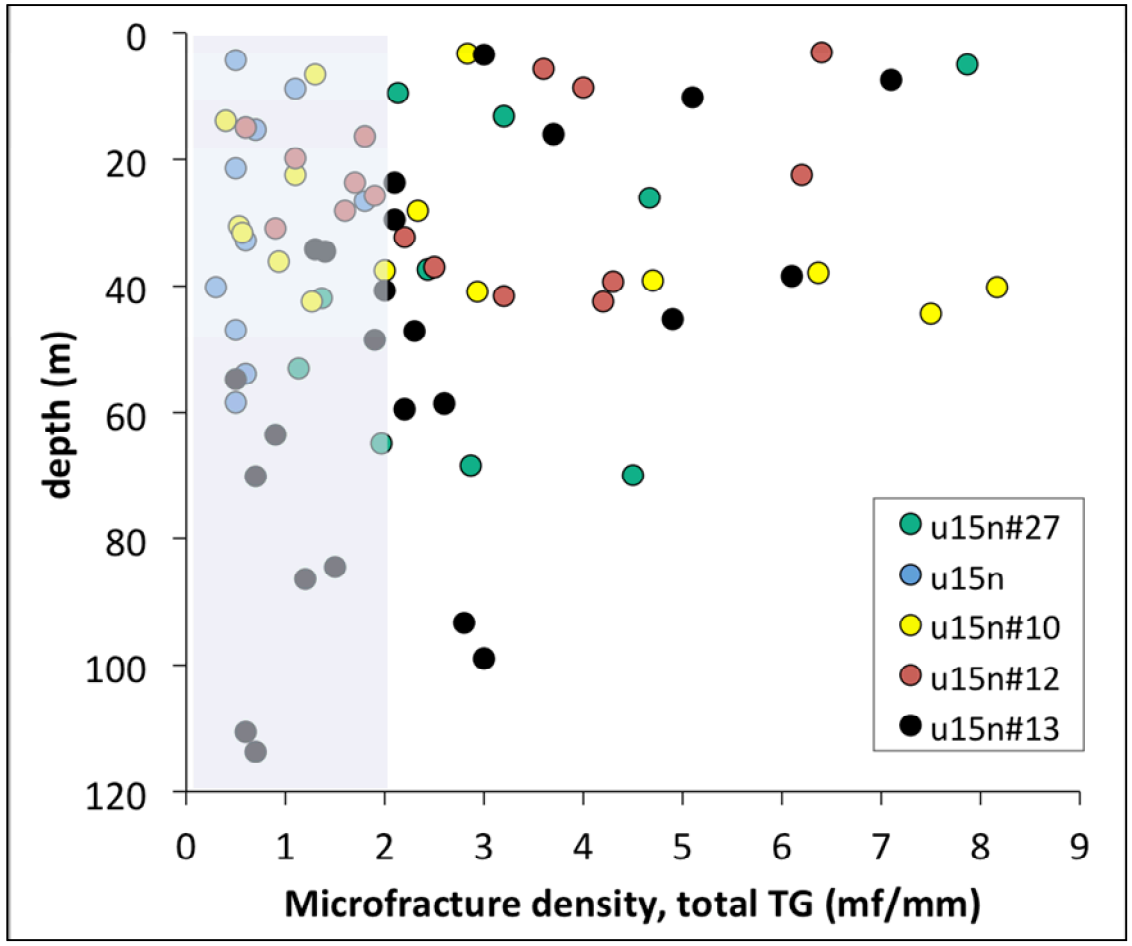
U15n13
148ft depth
Faulted granite



U15n13
34 ft depth
“Weathered” granite



Postshot



Core Scale Material Property Analyses

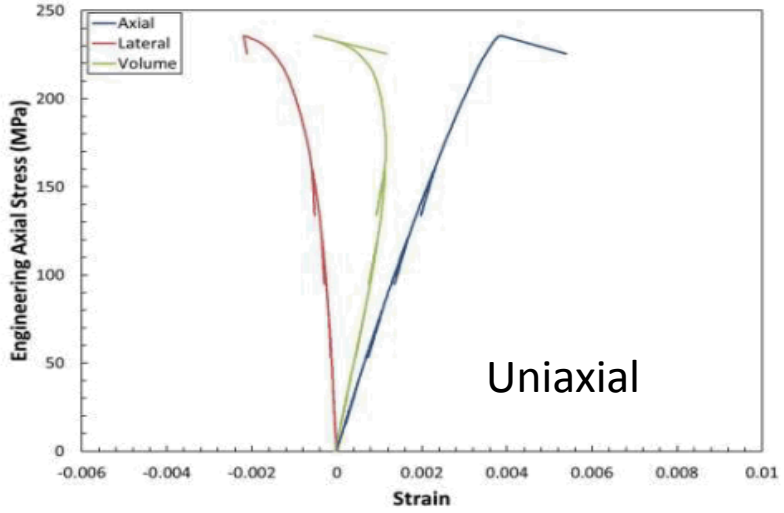
Uniaxial and Triaxial compression

Uniaxial

-Performed from source hole U-15n (pre SPE), U-15n#10 (post SPE2), U-15n#12 (post SPE3), U-15n#13 (post SPE3), and U-15n#27 (post SPE5)

-Used to compare to previous work on Climax Stock and understand rock strength variation between SPE events

-Hydrocode model development

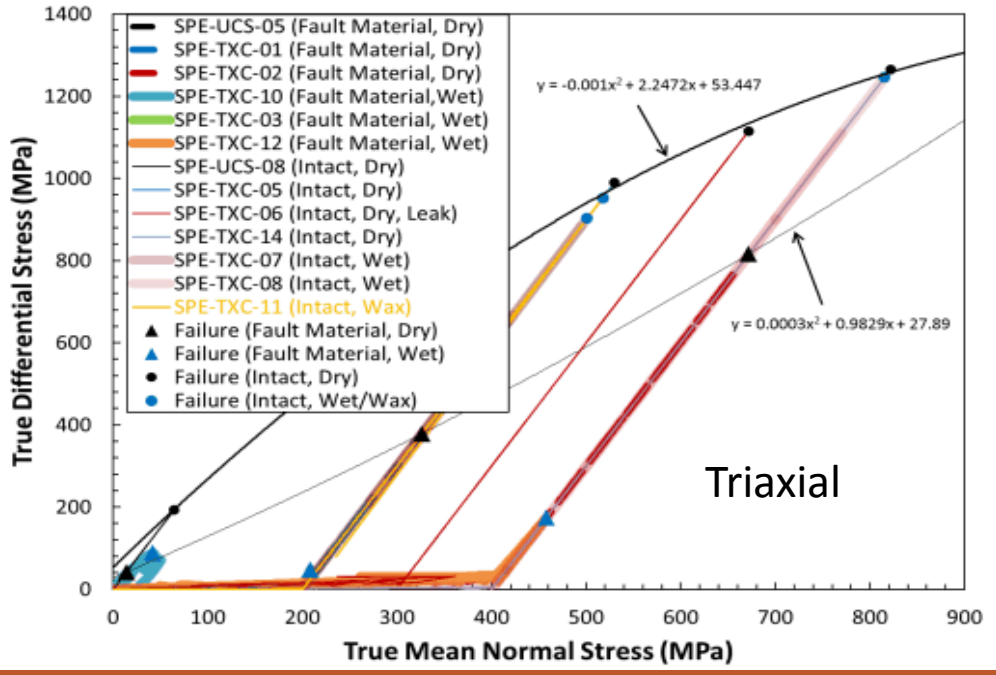


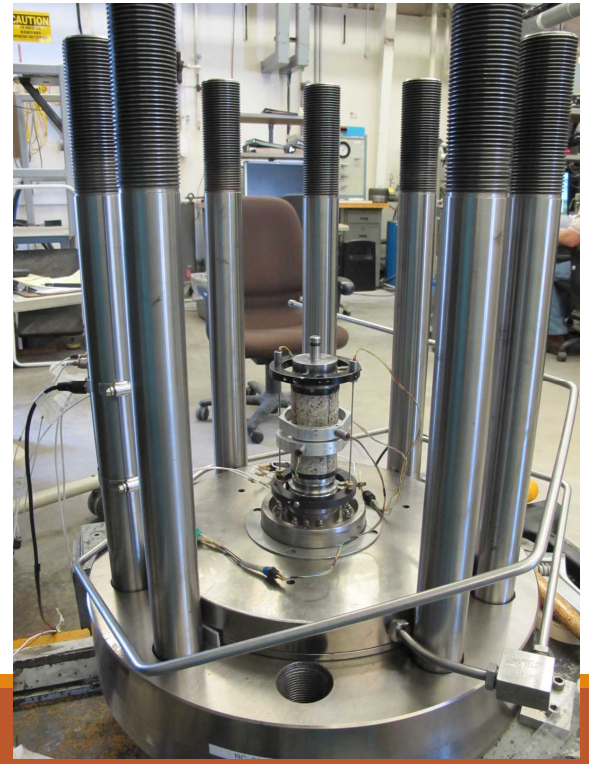
Triaxial

-Performed from source hole U-15n (pre SPE), U-15n#10 (post SPE2), and U-15n#27 (post SPE5)

-Used to establish failure envelope for intact and weathered (both wet and dry) materials

-Hydrocode model development





Core Scale Material Property Analyses

Dynamic/Quasi-static Disc Tension

Dynamic

-Performed from source hole U-15n (pre SPE) and U-15n#10 (post SPE2)

-Strain rate ~200/second

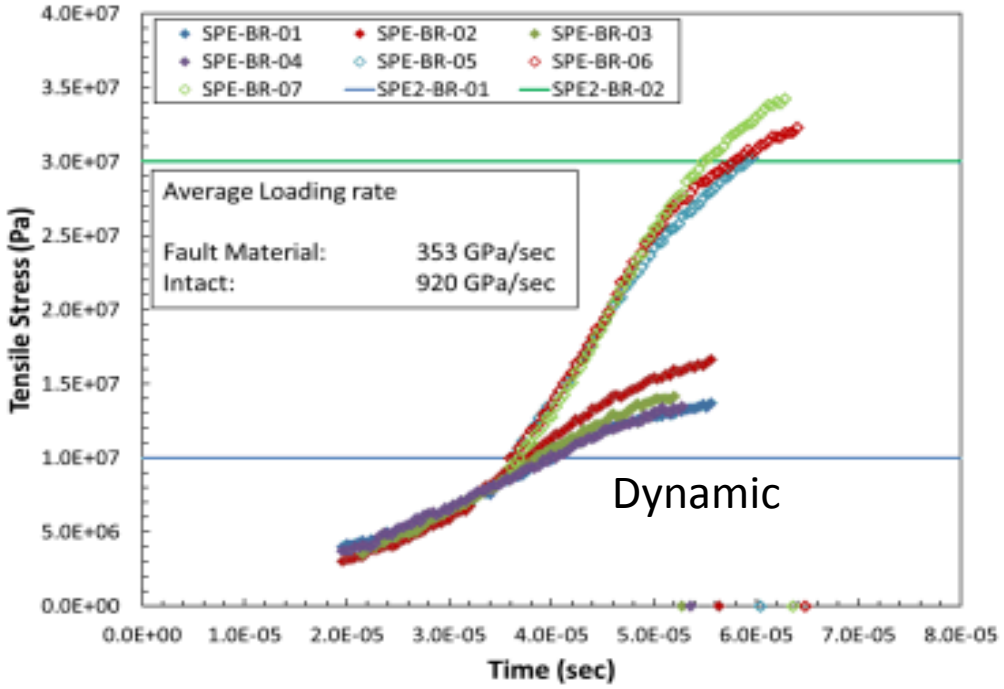
-FDEM development

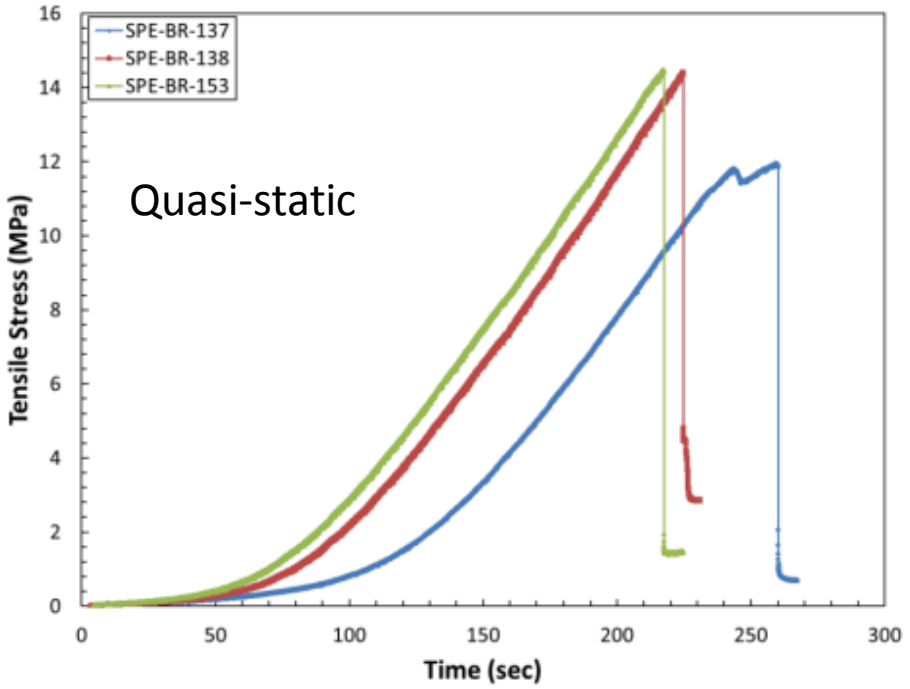
Quasi-static

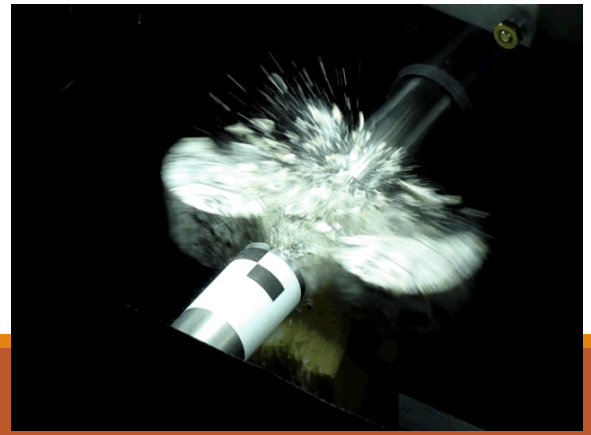
-Performed from source hole U-15n (pre SPE)

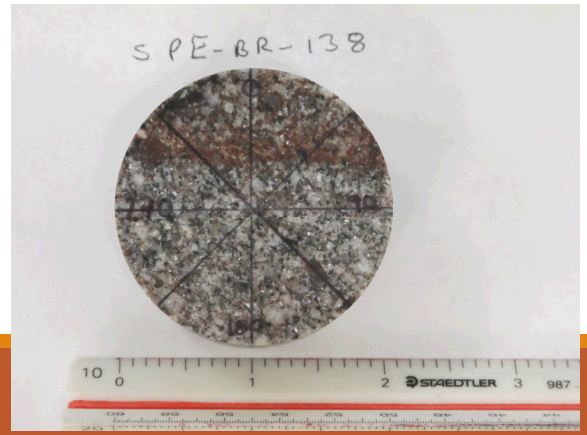
-Strain rate ~1E-4/second

-FDEM development



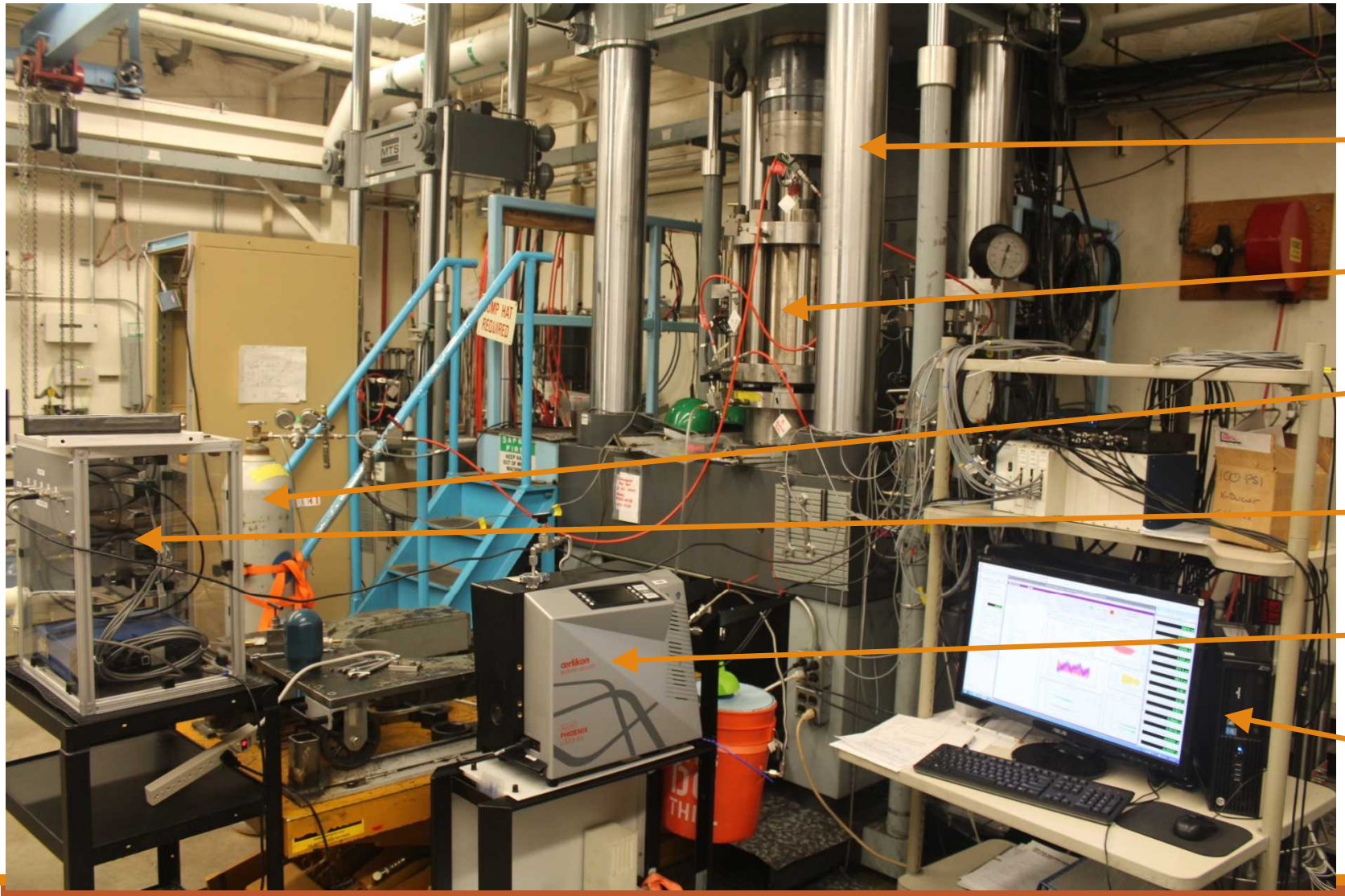






Core Scale Material Property Analyses

Triaxial compression to investigate permeability and damage relationship



Load frame

Pressure vessel

Upstream helium source

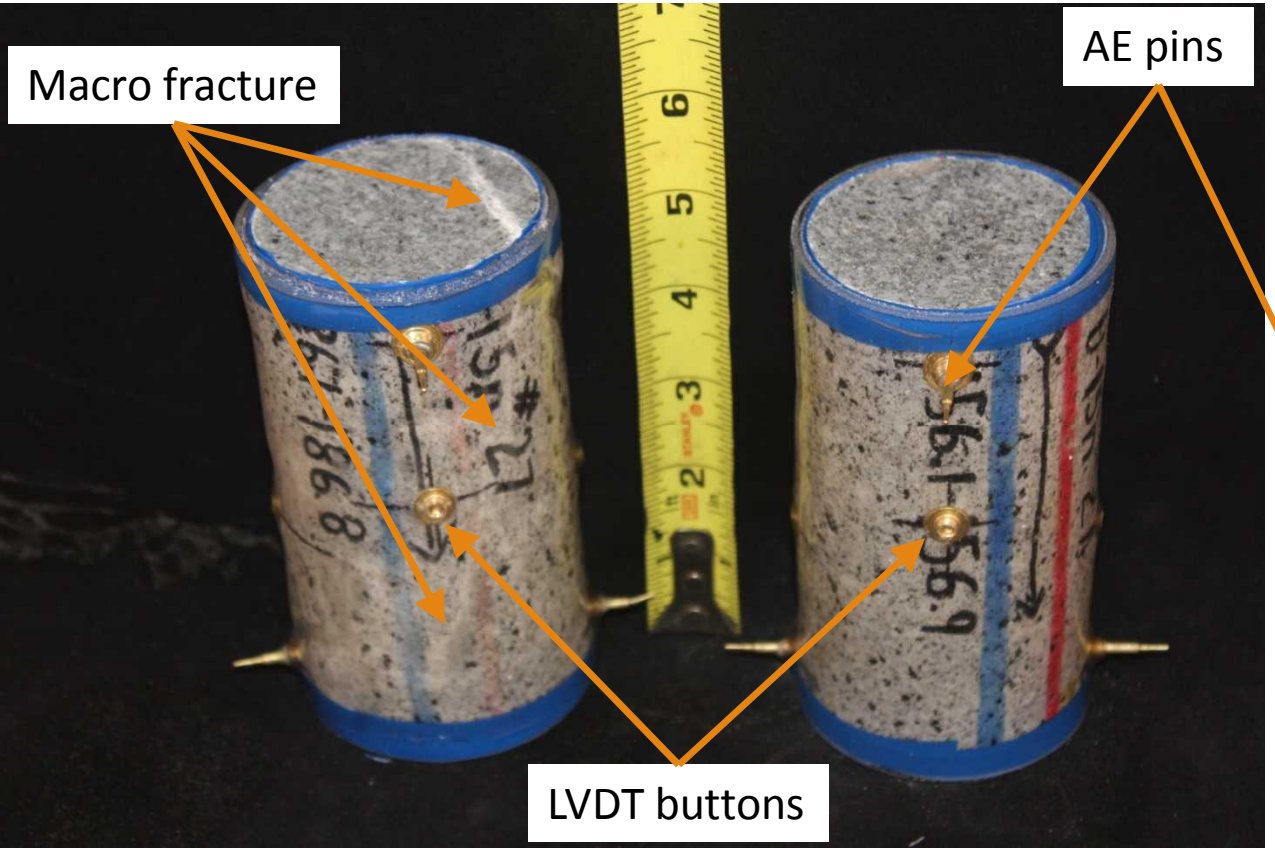
Flow bench

Helium leak detector

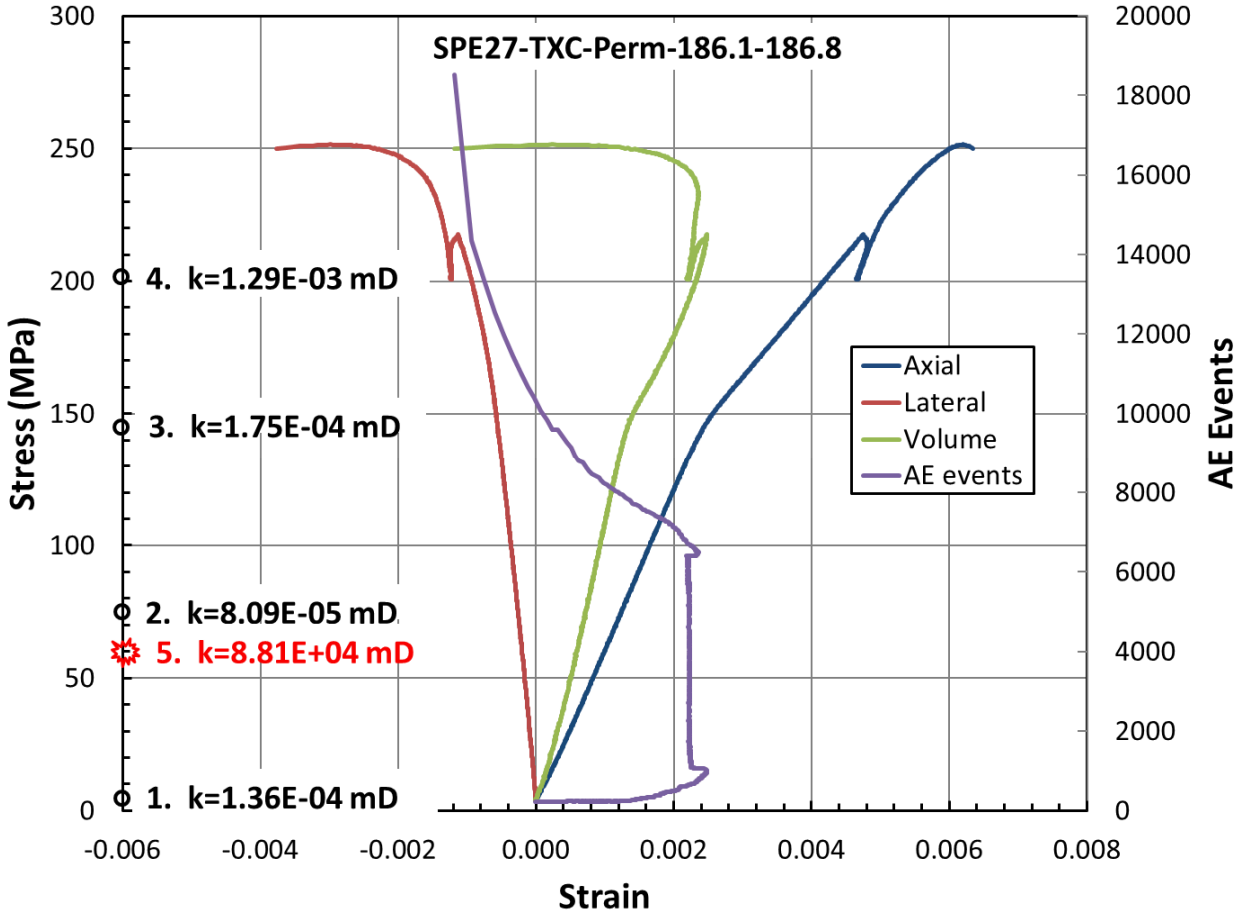
Data Acquisition System

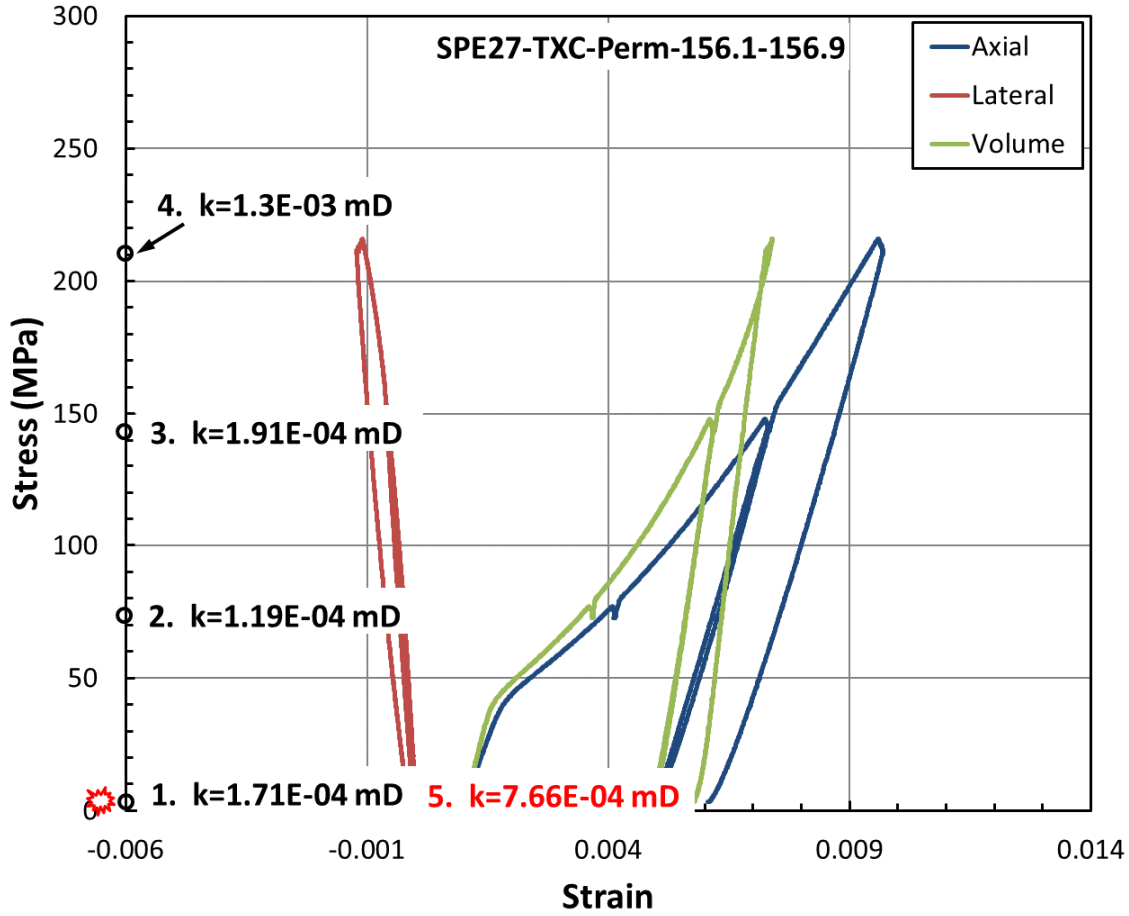
Core Scale Material Property Analyses

Triaxial compression to investigate permeability and damage relationship



Samples each photo (Left) SPE27-TXC-Perm-186.1-186.8 and (Right) SPE27-TXC-Perm-156.1-156.9
Buttons mount LVDT's to measure radial strain
Pins record Acoustic Emissions

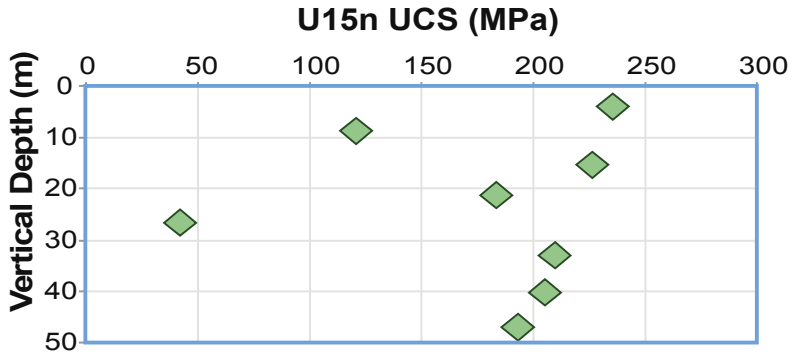


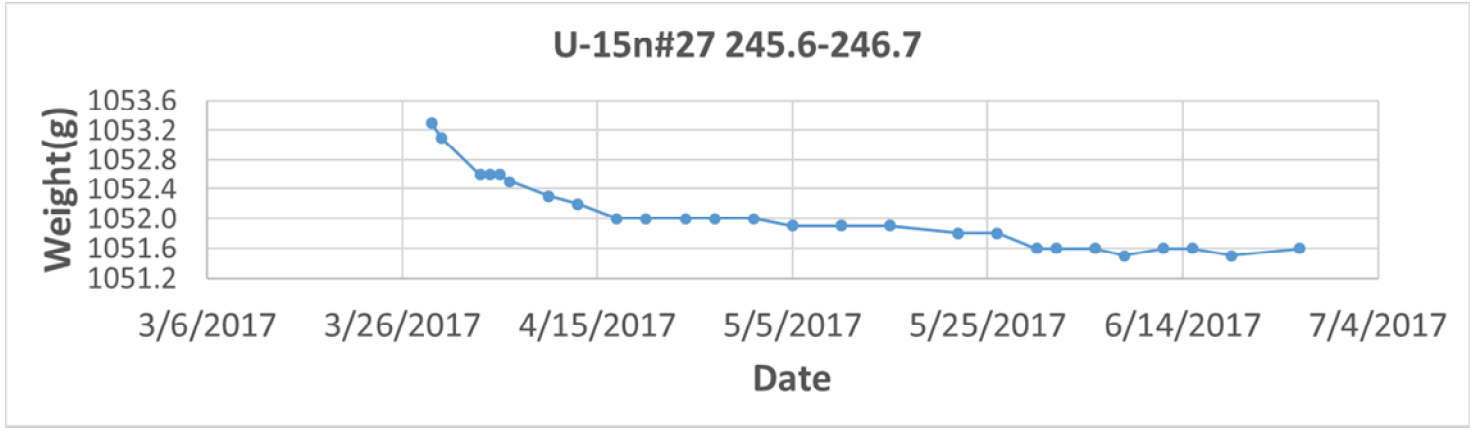


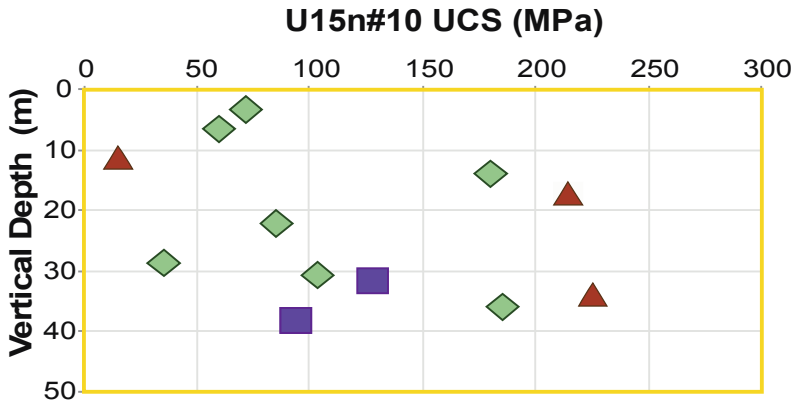
- Baseline permeability ~1E-04mD taken at 3.5 MPa hydrostatic pressure
- Permeability decreases at 75 MPa Axial Stress
- Permeability increases at 145 MPa (above hydrostatic baseline) and then again at 210 MPa Axial Stress (one order of magnitude above baseline)
- Sample SPE27-TXC-Perm-186.1-186.8 taken to failure. Post failure permeability is seven orders of magnitude above previous measured permeability
- Sample SPE27-TXC-Perm-156.1-156.9 unloaded after Axial Stress of 210 MPa. Hydrostatic permeability now half an order of magnitude greater than undamaged hydrostatic permeability

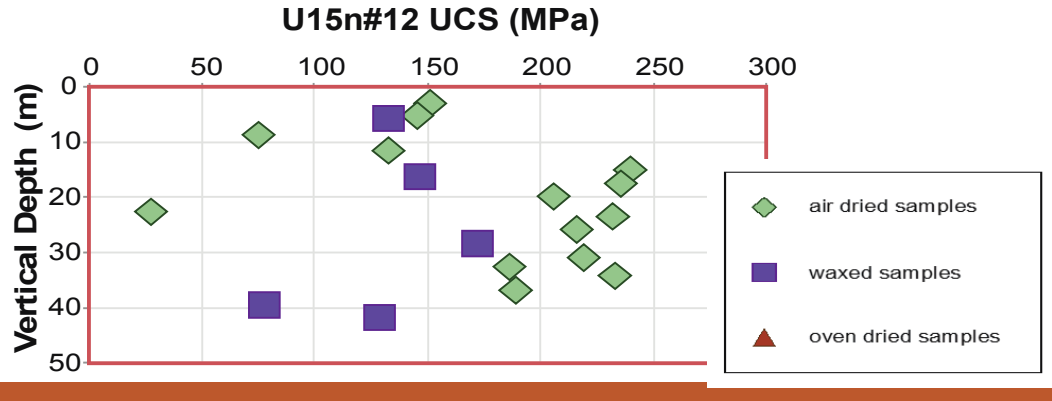
Core Scale Material Property Analyses

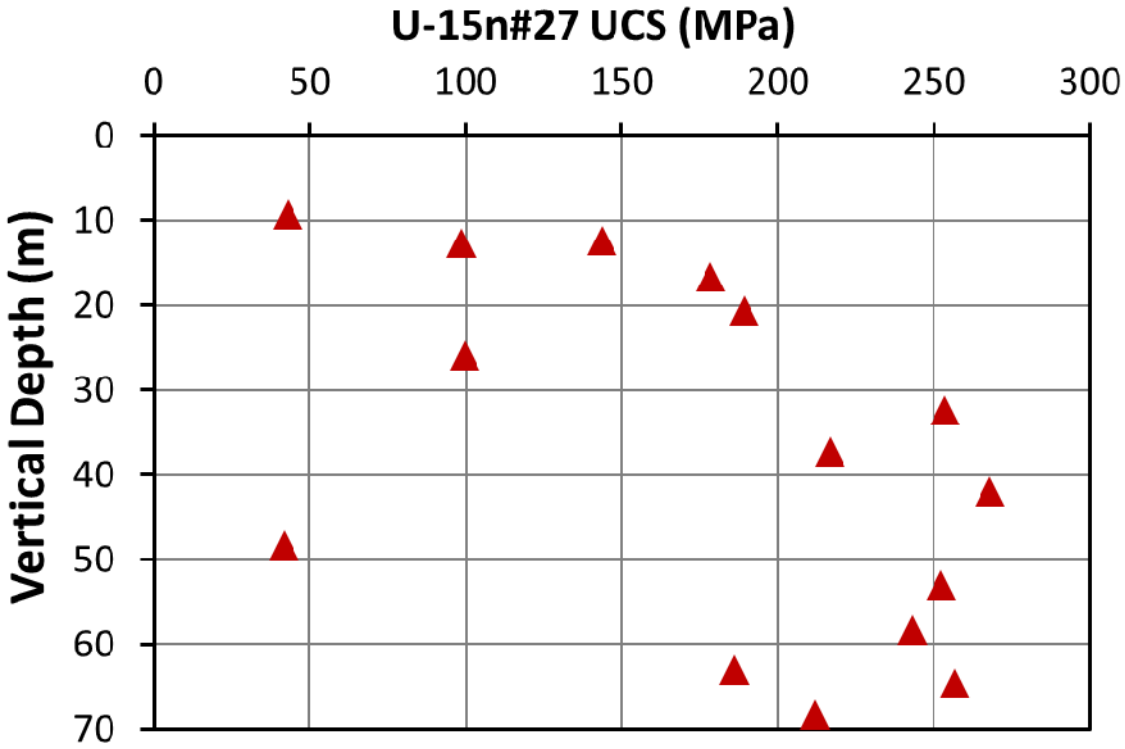
Unconfined compressive strength varies with water content





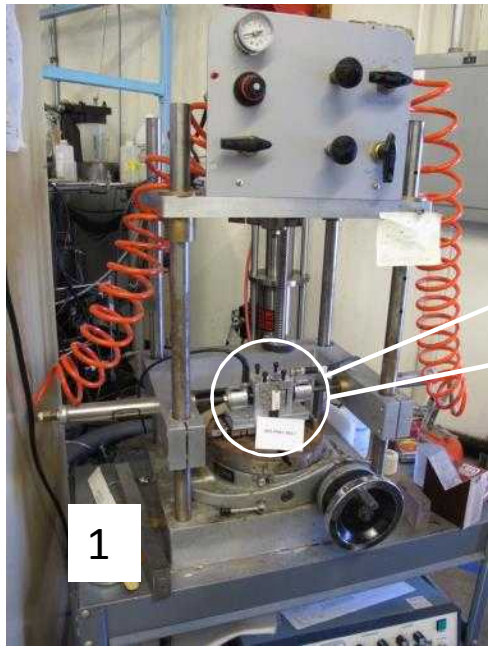


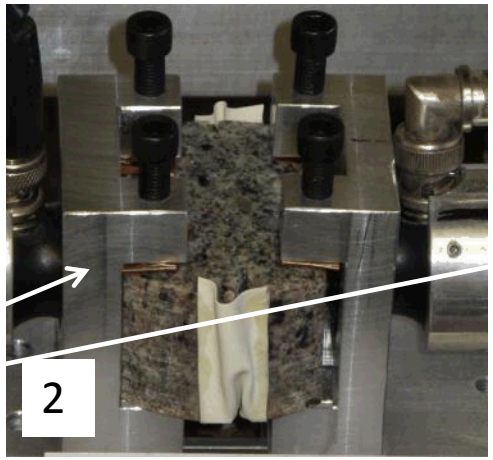




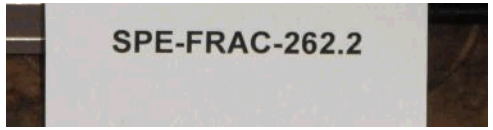
Core Scale Fracture Property Analyses

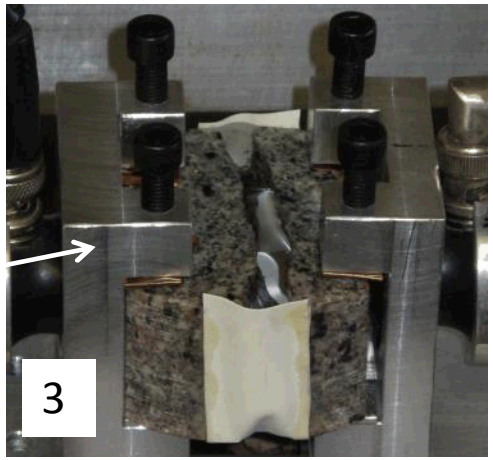
P&S velocity as a function of fracture aperture with water as coupling medium



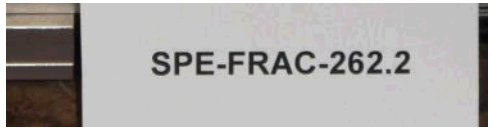


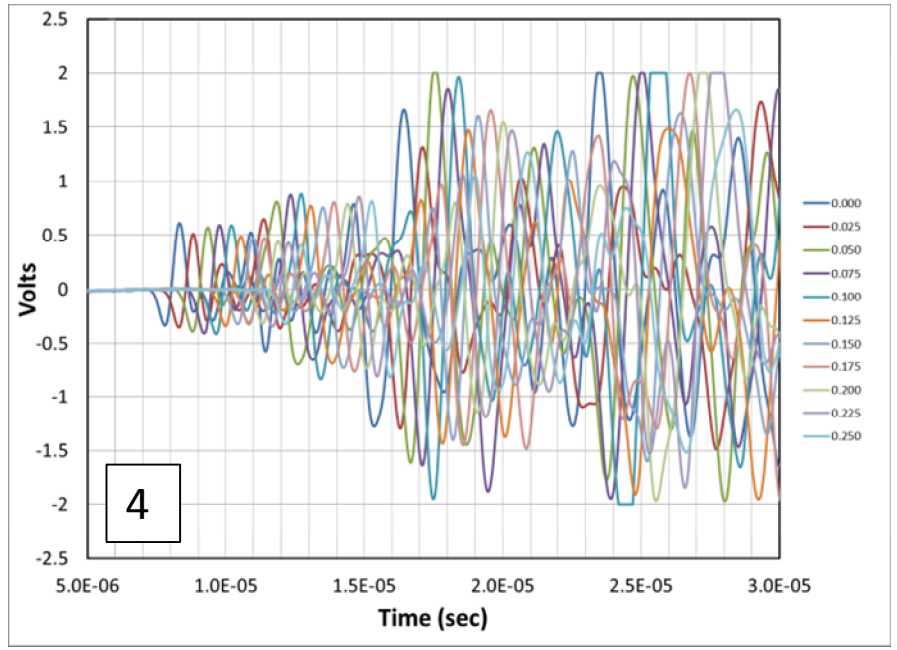
Water filled closed gap.

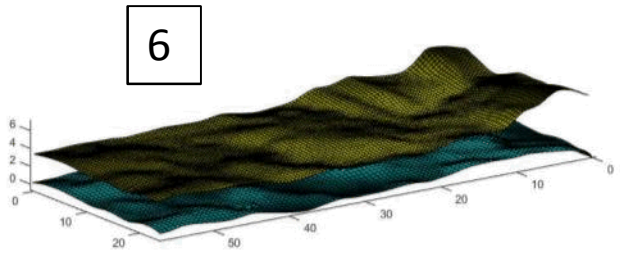


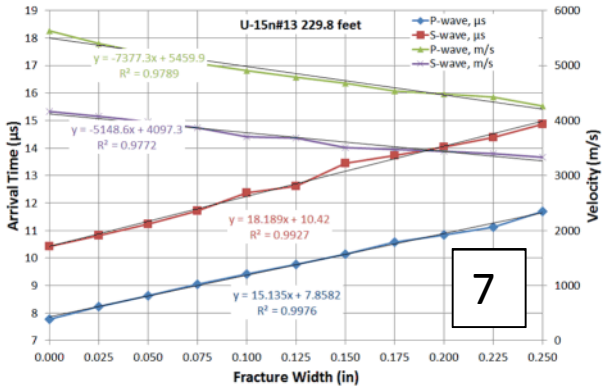


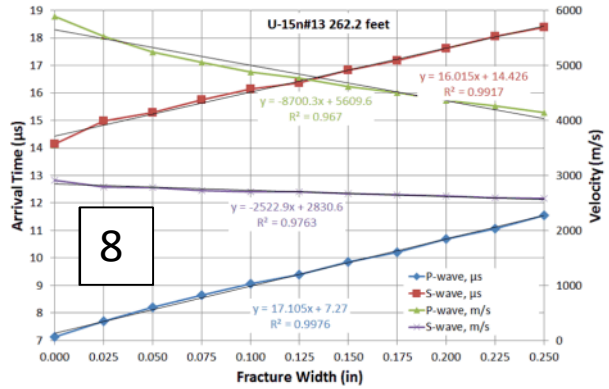
0.250” gap filled with water.







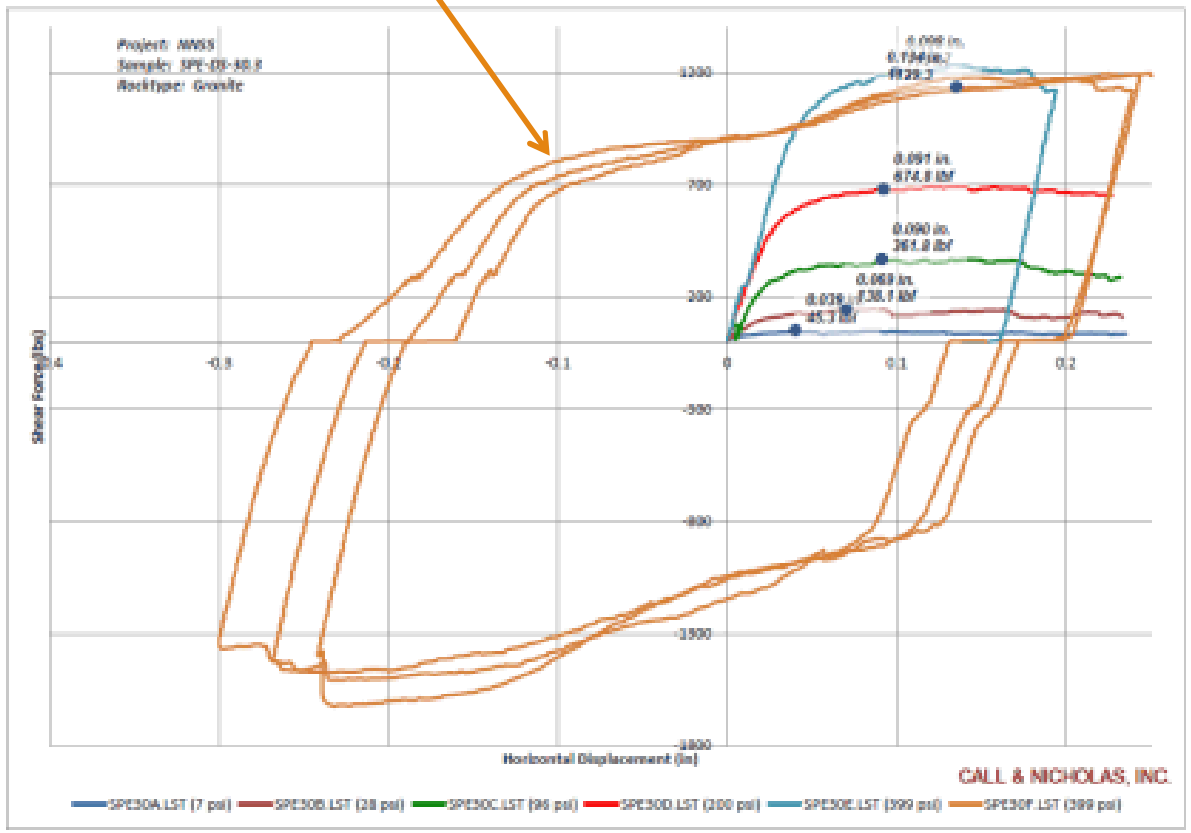


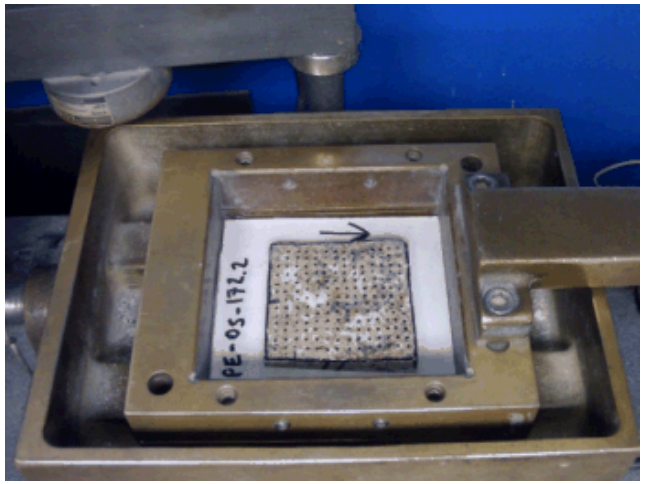


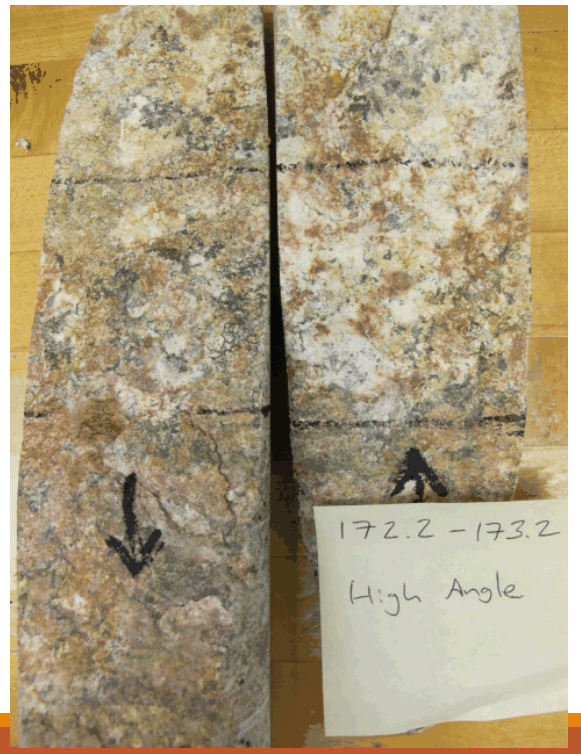
Core Scale Fracture Property Analyses

Direct Shear on Natural Fractures

- Core from source hole U-15n (pre SPE) and U-15n#10 (post SPE2)
- Determine Friction angle and cohesion of natural fractures
- Dry and saturated testing conditions
- Repetitive shearing performed



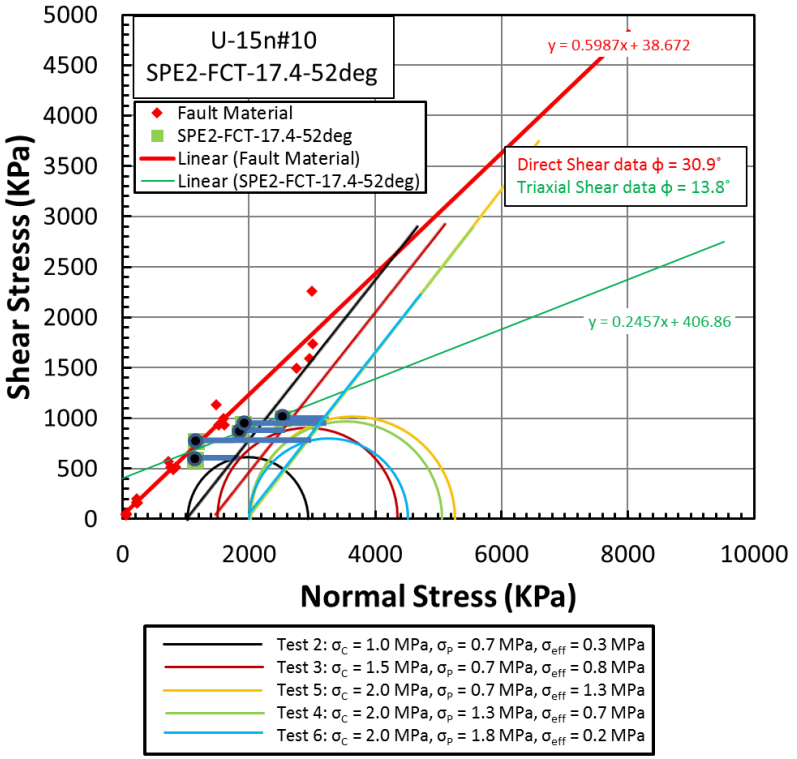


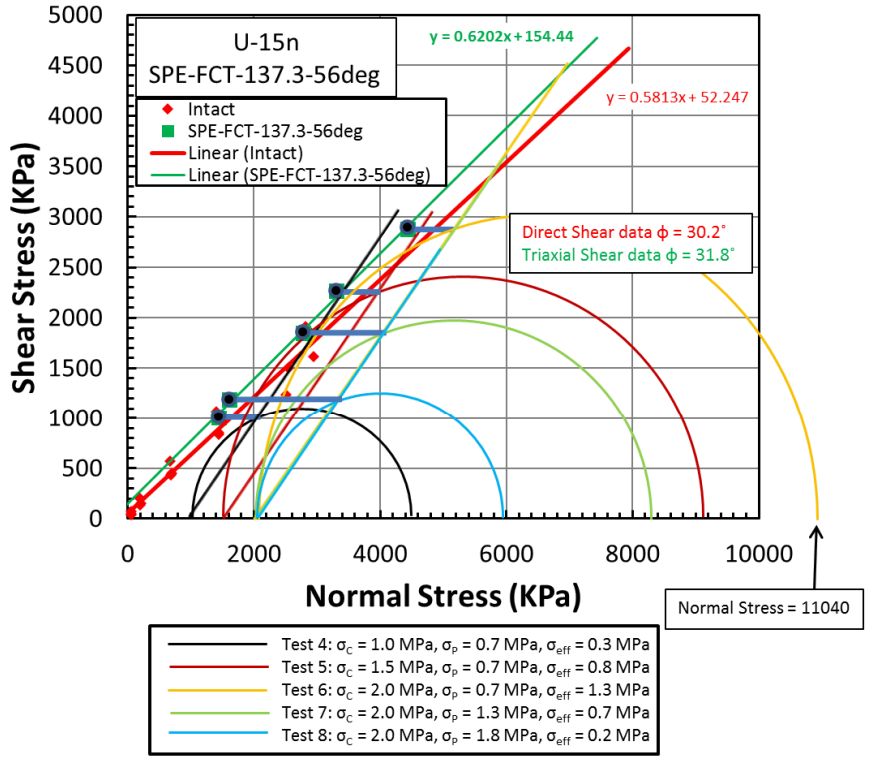


Core Scale Fracture Property Analyses

Triaxial Shear on Natural Fractures

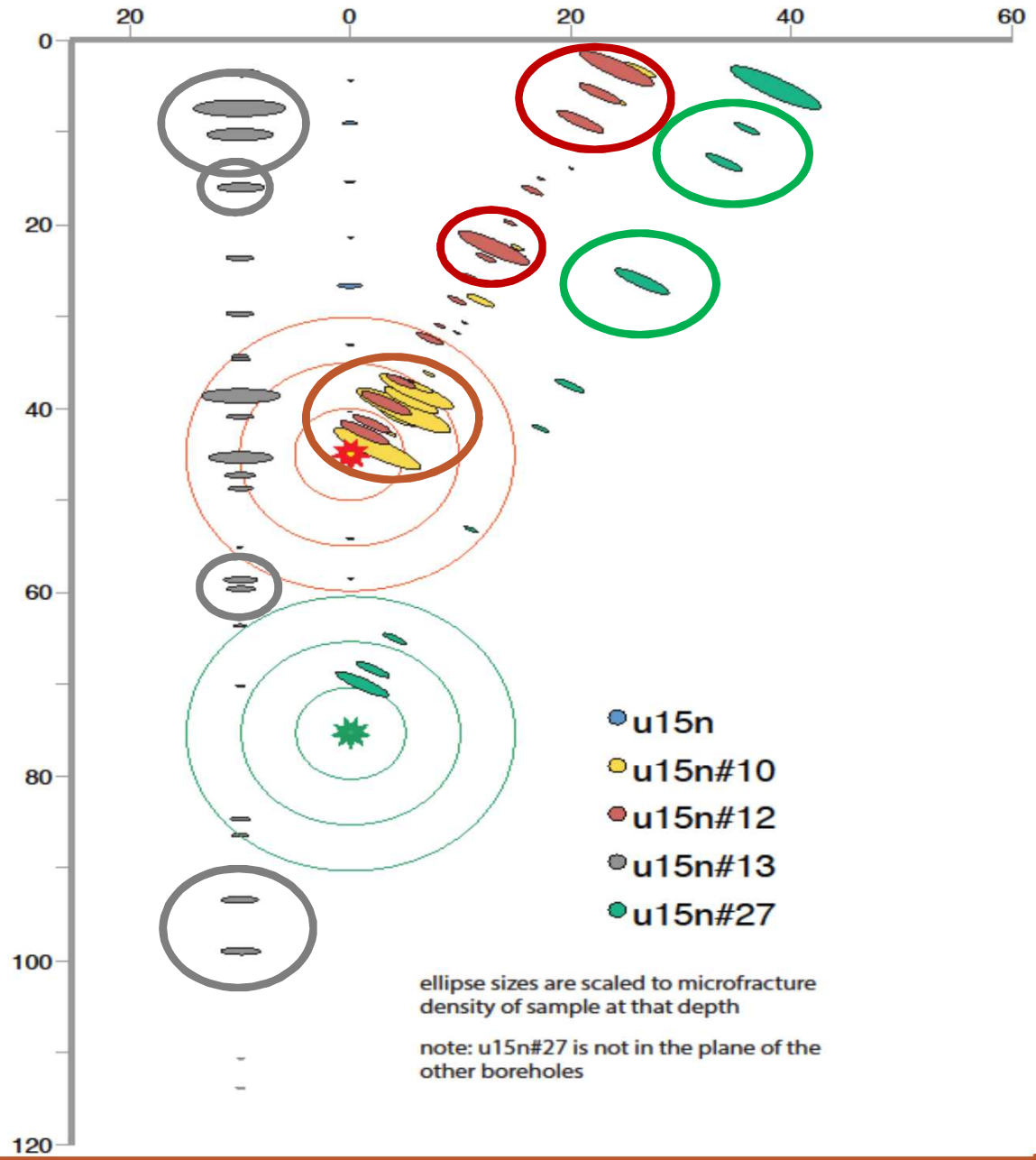
- Core from source hole U-15n (pre SPE) and U-15n#10 (post SPE2)
- Determine Friction angle and cohesion
- Incorporate fracture surface fluid pressure and confining pressure
- Characterization of wet weathered material possible

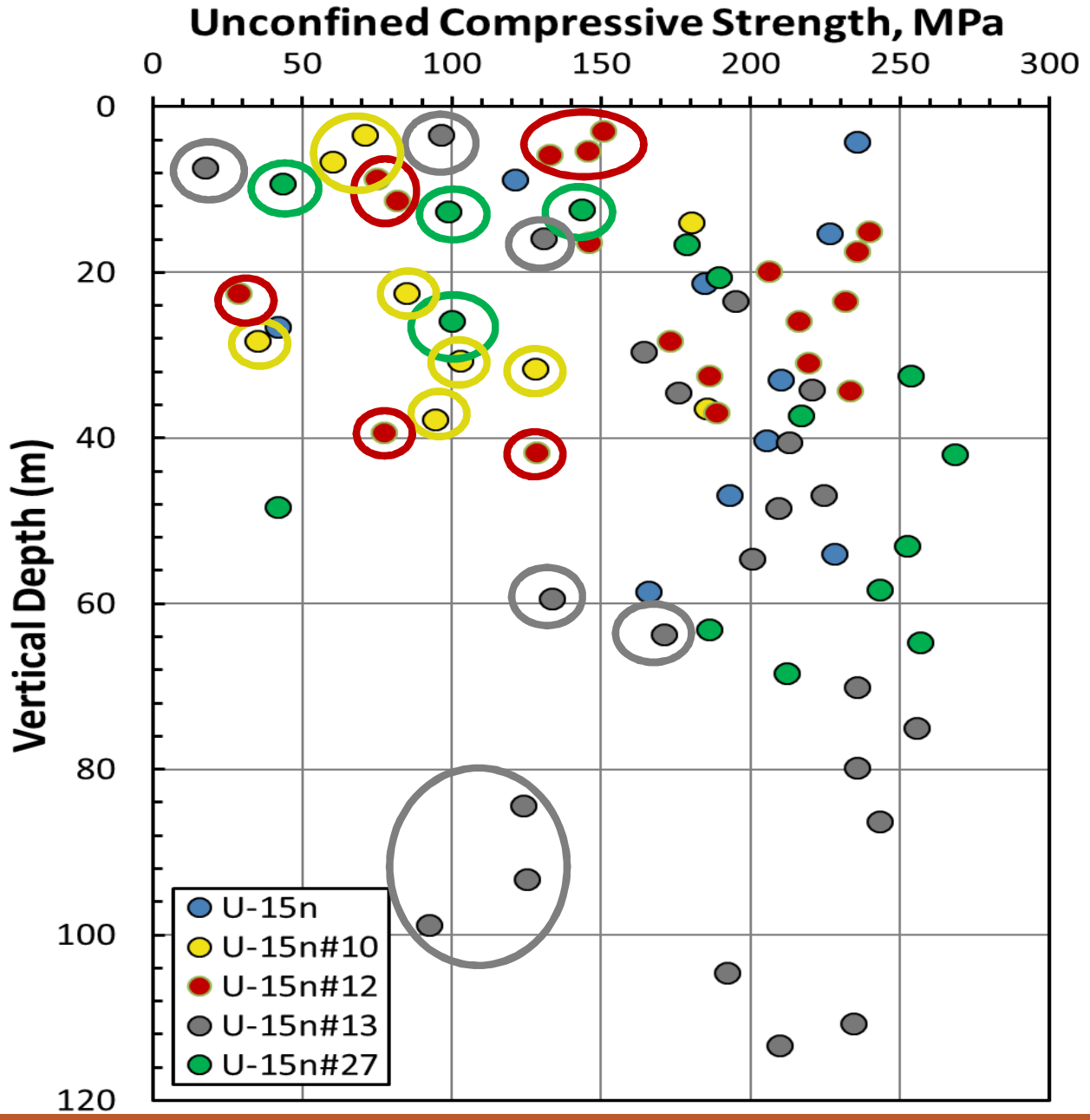




Grooves cut in rock to facilitate transmission of pore fluid to natural fracture surface.

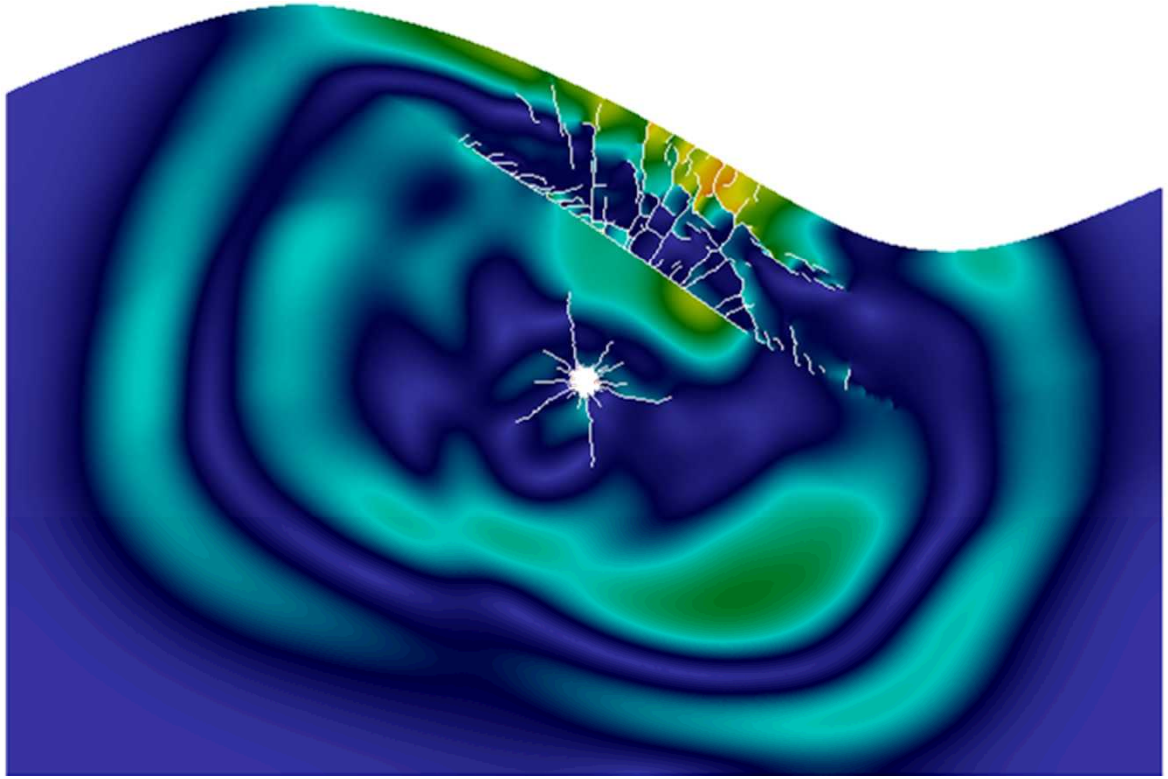
Linking Micro to Core Scale Material Properties



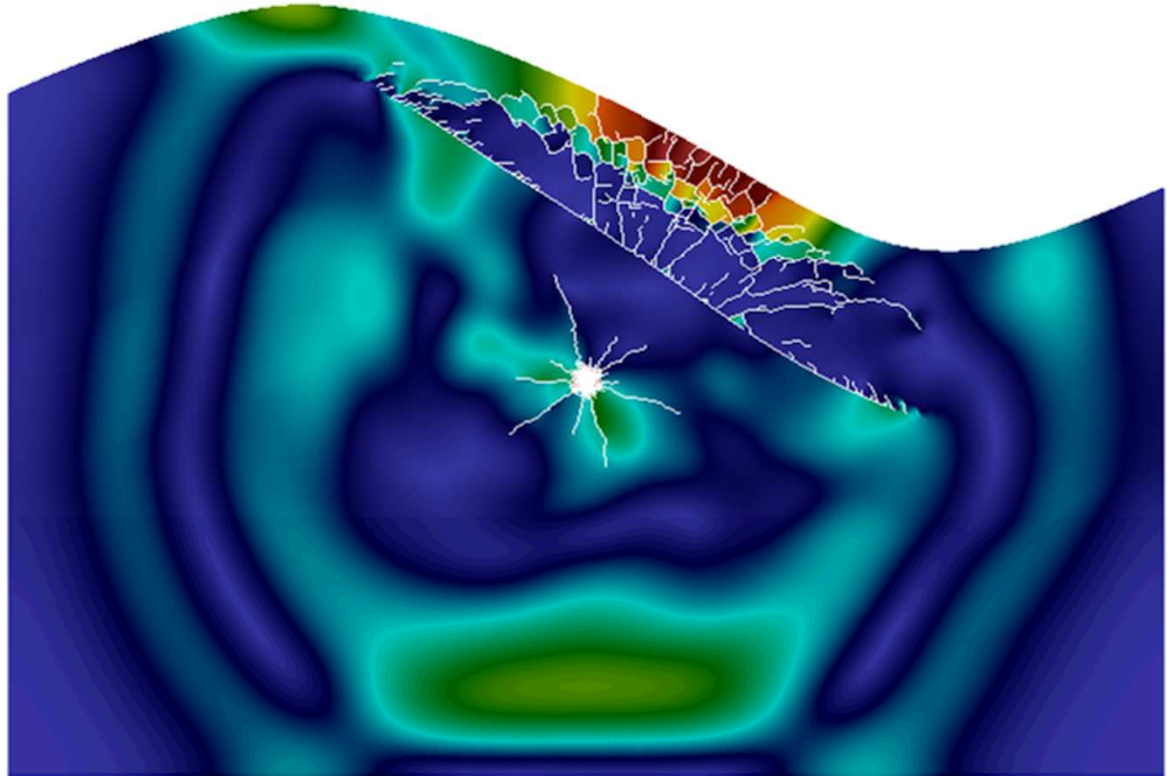


Micro-scale Material and Fracture Property Analyses

Optical microscopy data incorporated into models

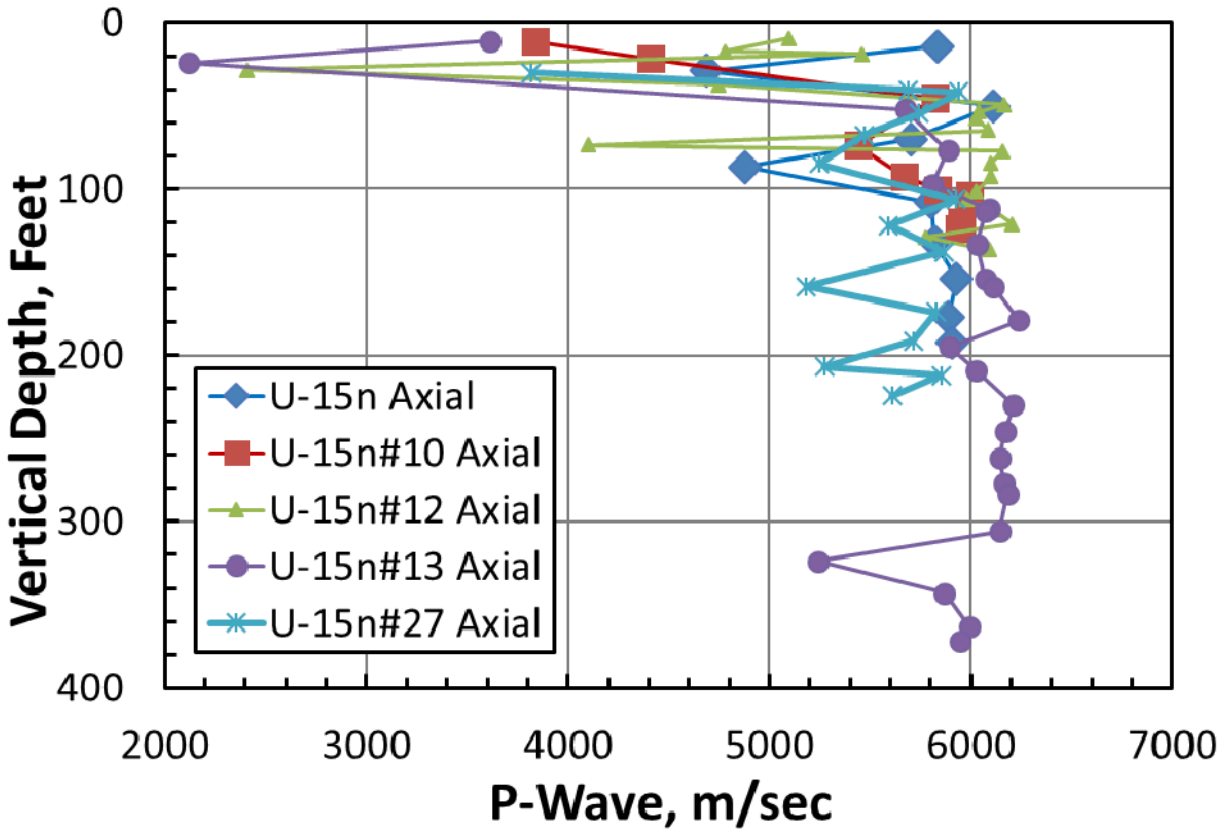


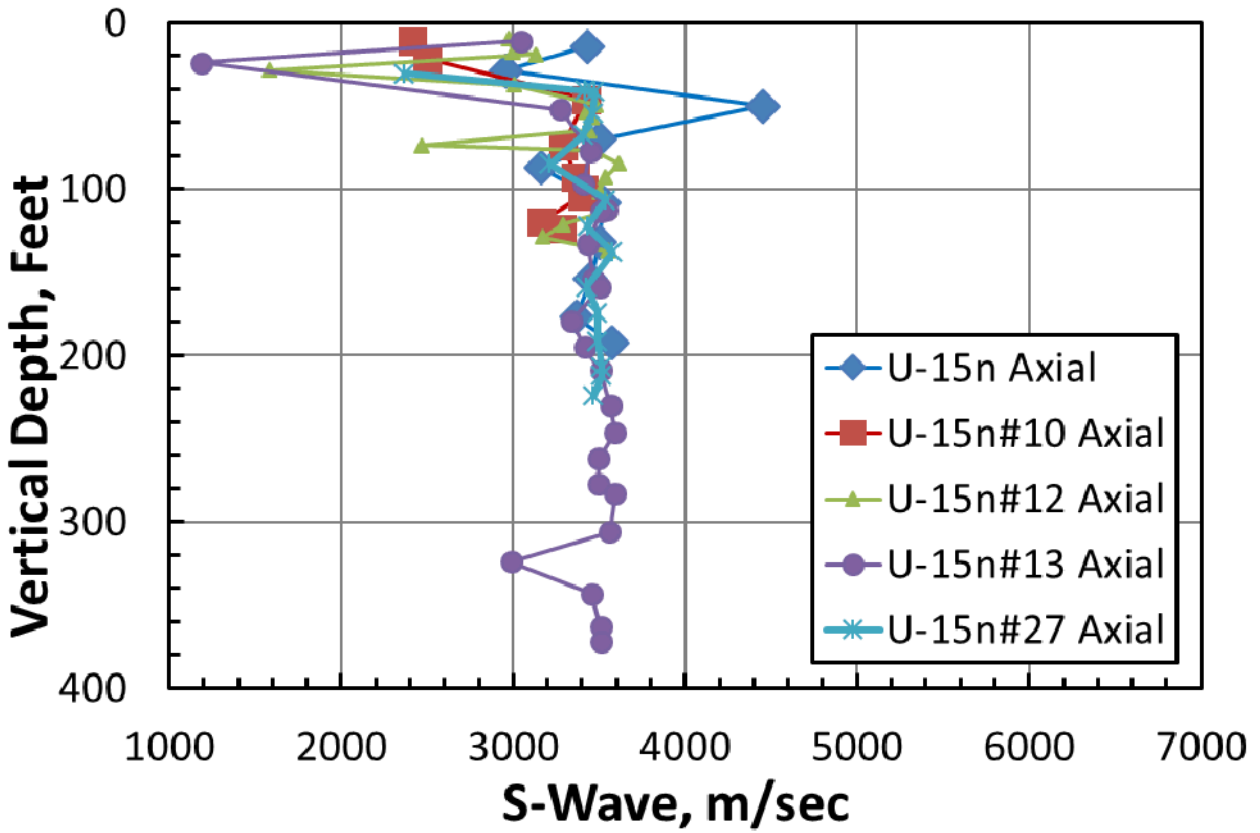
Anisotropic Medium

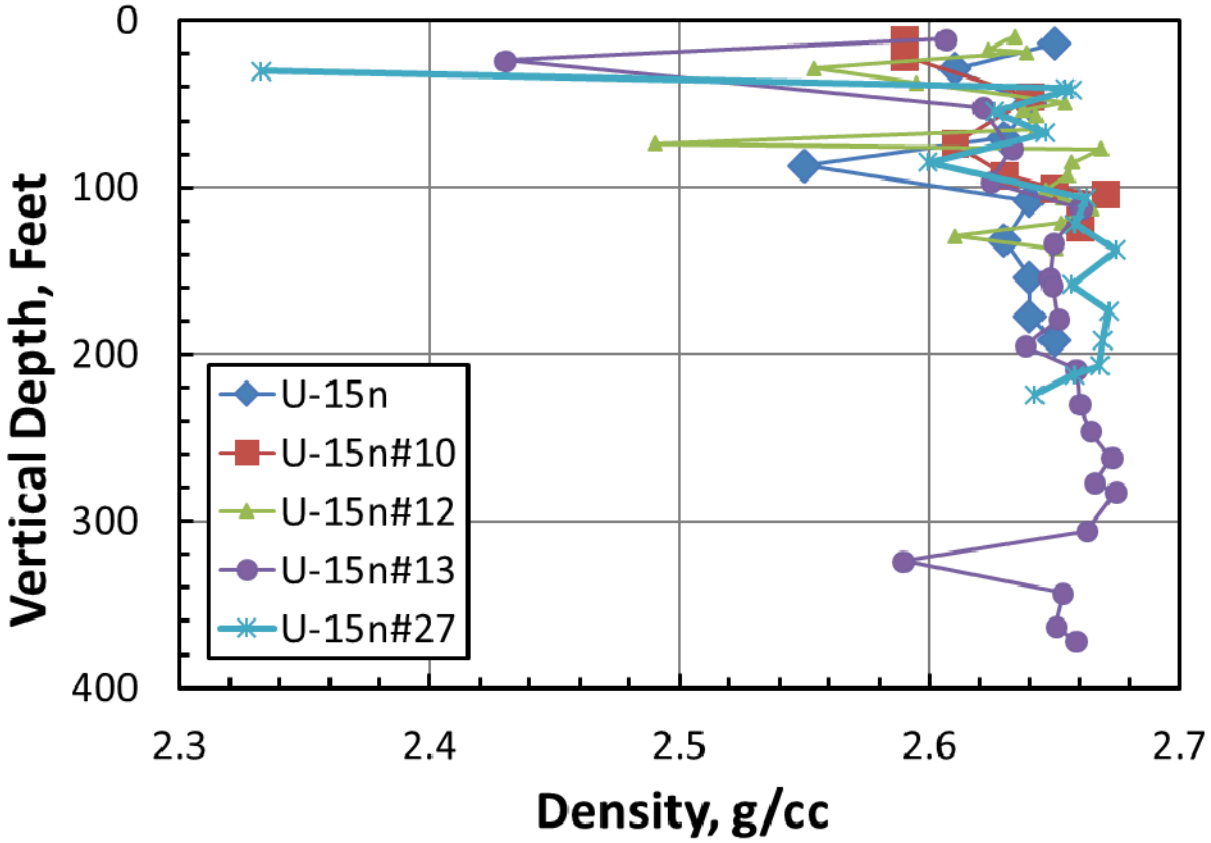


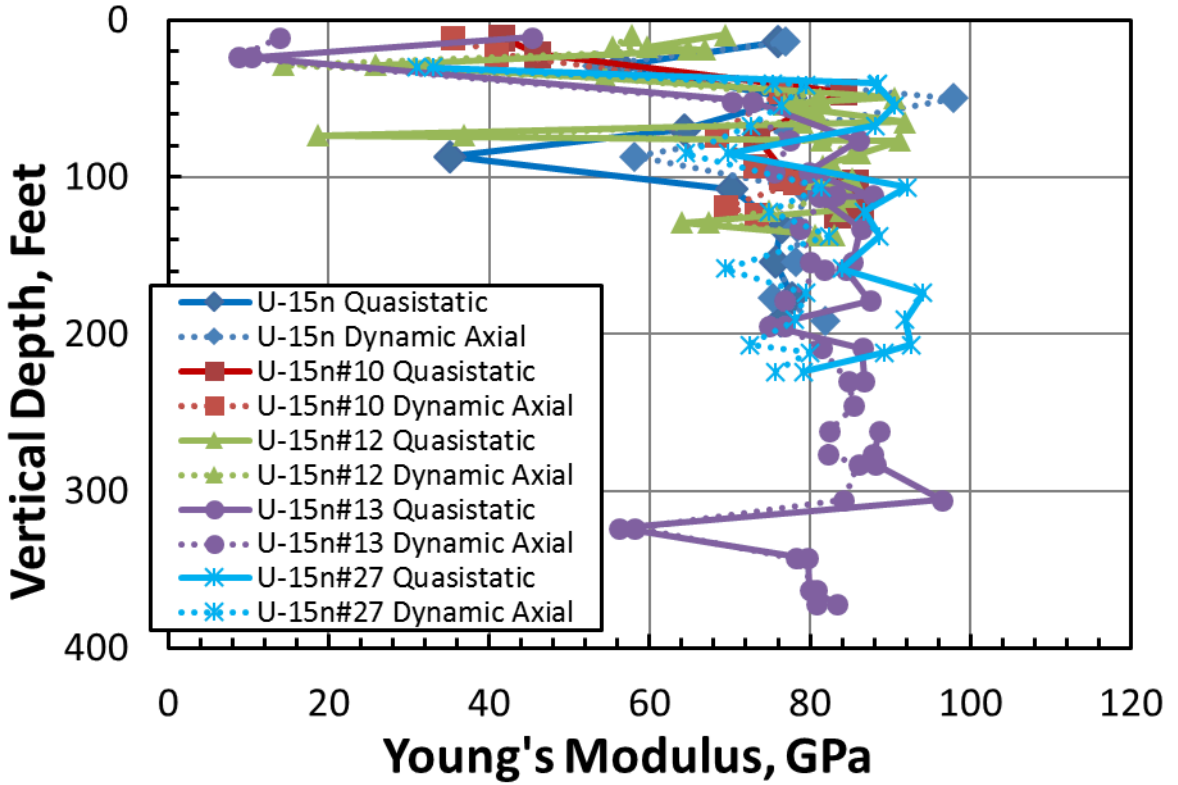
Isotropic Medium

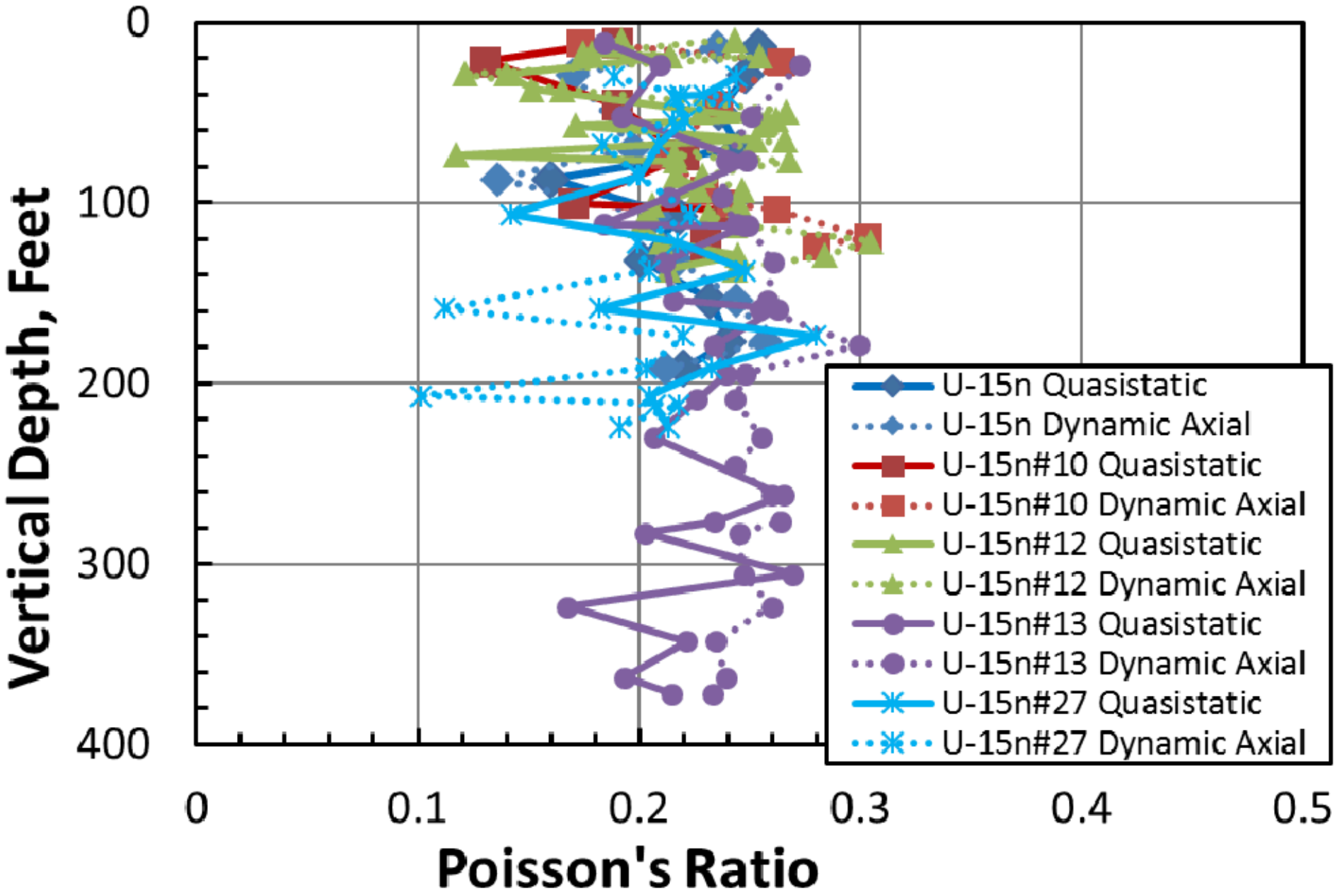
Backup slides

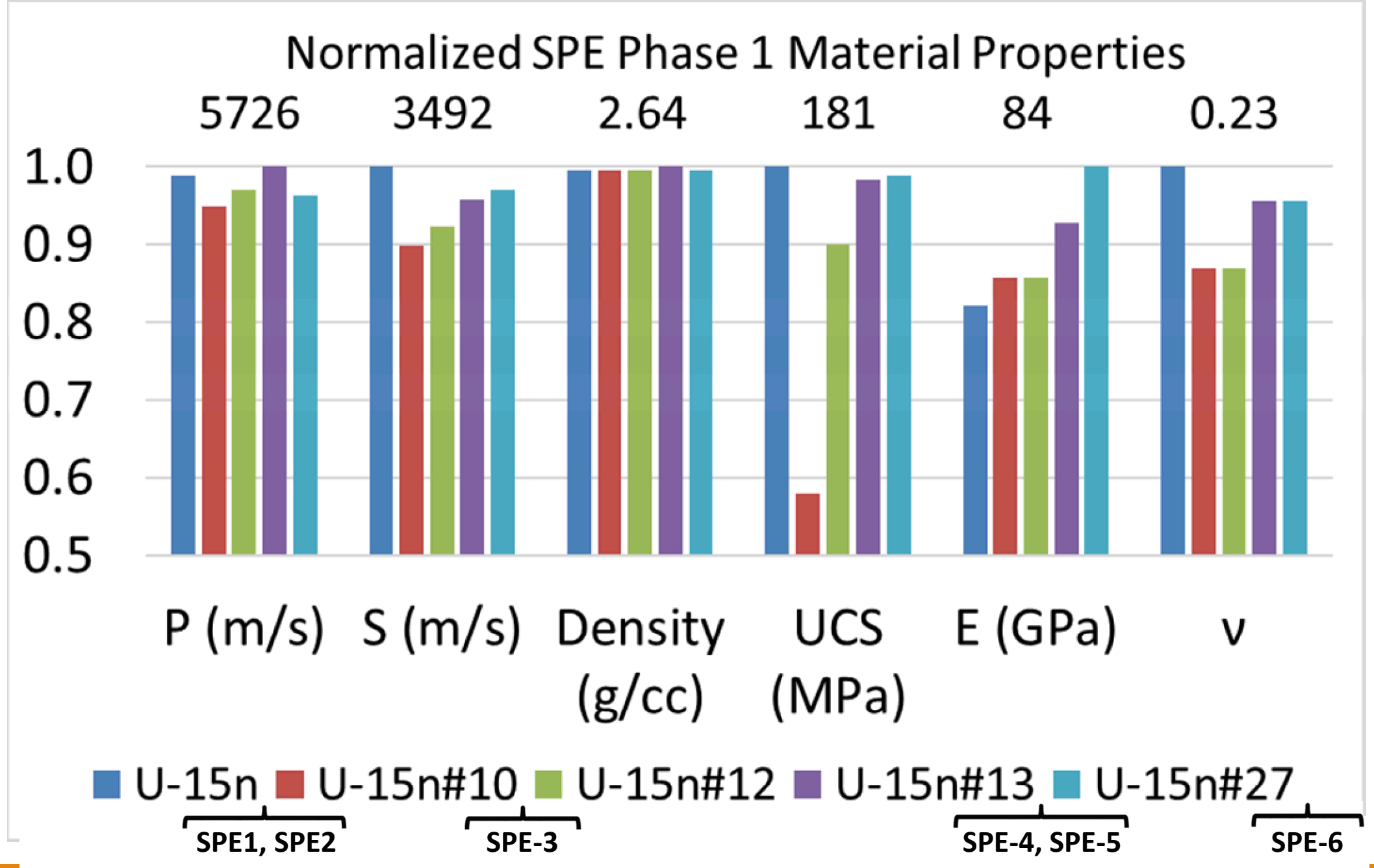

Vertical Depth, Feet
0
100
200
300
400
2000
3000
4000
5000
6000
7000
P-Wave, m/sec
U-15n Axial
U-15n#10 Axial
U-15n#12 Axial
U-15n#13 Axial
U-15n#27 Axial


Vertical Depth, Feet
0
100
200
300
400
1000
2000
3000
4000
5000
6000
7000
S-Wave, m/sec
U-15n Axial
U-15n#10 Axial
U-15n#12 Axial
U-15n#13 Axial
U-15n#27 Axial


Vertical Depth, Feet
0
100
200
300
400
2.3
2.4
2.5
2.6
2.7
Density, g/cc
U-15n
U-15n#10
U-15n#12
U-15n#13
U-15n#27


Vertical Depth, Feet
0
100
200
300
400
0
20
40
60
80
100
120
Young's Modulus, GPa
U-15n Quasistatic
U-15n Dynamic Axial
U-15n#10 Quasistatic
U-15n#10 Dynamic Axial
U-15n#12 Quasistatic
U-15n#12 Dynamic Axial
U-15n#13 Quasistatic
U-15n#13 Dynamic Axial
U-15n#27 Quasistatic
U-15n#27 Dynamic Axial


Vertical Depth, Feet
0
100
200
300
400
0
0.1
0.2
0.3
0.4
0.5
Poisson's Ratio
U-15n Quasistatic
U-15n Dynamic Axial
U-15n#10 Quasistatic
U-15n#10 Dynamic Axial
U-15n#12 Quasistatic
U-15n#12 Dynamic Axial
U-15n#13 Quasistatic
U-15n#13 Dynamic Axial
U-15n#27 Quasistatic
U-15n#27 Dynamic Axial


Normalized SPE Phase 1 Material Properties
5726
3492
2.64
181
84
0.23
1.0
0.9
0.8
0.7
0.6
0.5
P (m/s)
S (m/s)
Density (g/cc)
UCS (MPa)
E (GPa)
v
U-15n
U-15n#10
U-15n#12
U-15n#13
U-15n#27
SPE1, SPE2
SPE-3
SPE-4, SPE-5
SPE-6