Understanding Pore Compliance and Poroelasticity in Reservoirs (& Beyond): A Geophysical Approach
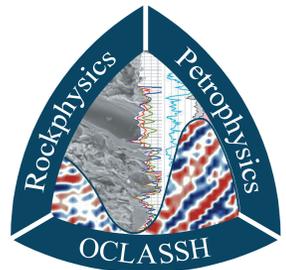
Jared Atkinson – presenting works of
Anvar Guliyev, Azar Hasanov, Kurt Livo, Cesar Mapeli, and Mandy Schindler

Center for Rock Abuse, Colorado School of Mines

Motivation

- Pore compliance is commonly the main cause of pressure sensitivity

- A multi-physics approach helps assign and constrain causative mechanisms for rock physics models

- This talk presents:
  - Simultaneous acoustic and electrical anisotropy measurements under pressure
  - Cyclic stress and poroelastic parameters
  - NMR T2 relaxations as functions of pressure in water-saturated rocks
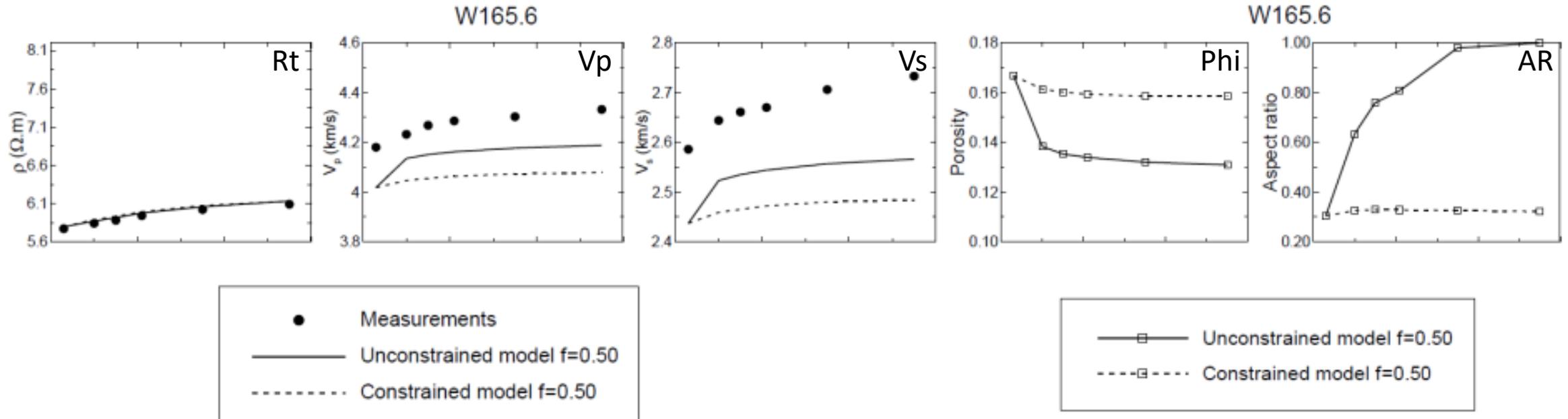 - Strain localization images acquired with MXCT and acoustic measurements

SIMULTANEOUS ACOUSTIC AND ELECTRICAL ANISOTROPY

Joint Inversion of Acoustic and Electrical Properties

Resistivity and Acoustic Velocities Fitting

W165.6

Porosity and Aspect Ratio Estimation

W165.6

- Measurements
- —— Unconstrained model f=0.50
- ------ Constrained model f=0.50

- ——⊟—— Unconstrained model f=0.50
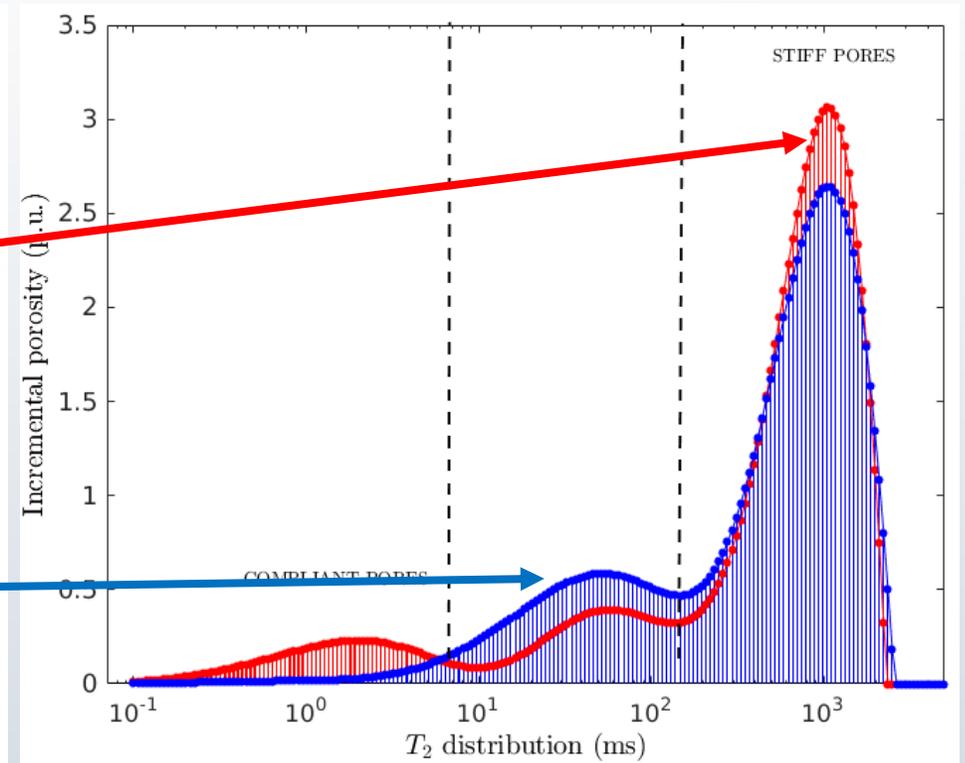- ----⊟---- Constrained model f=0.50
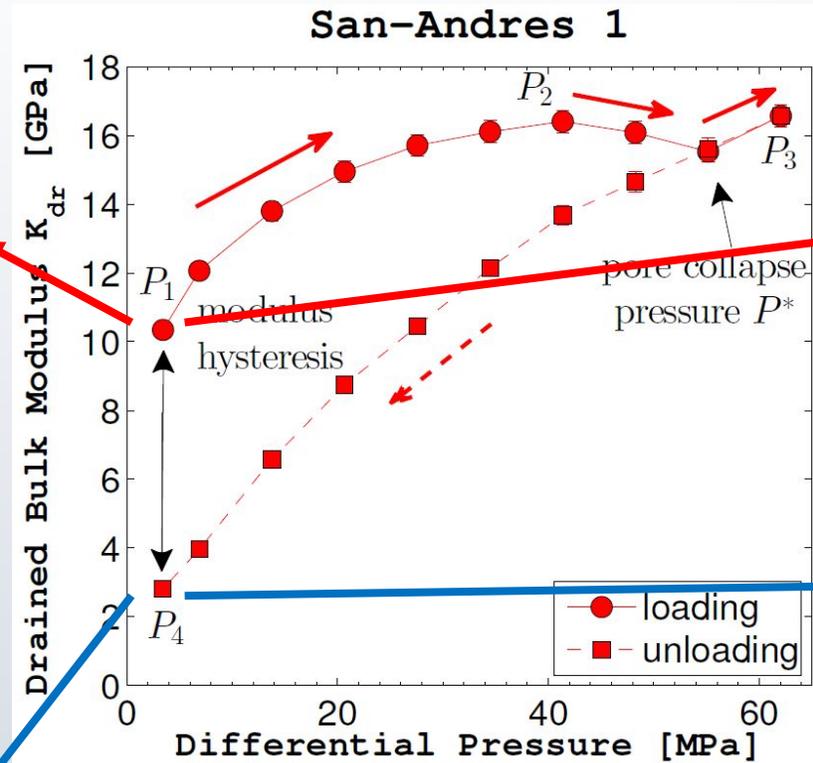
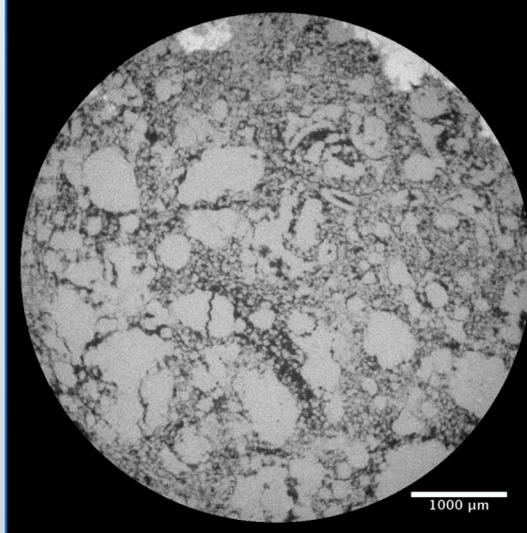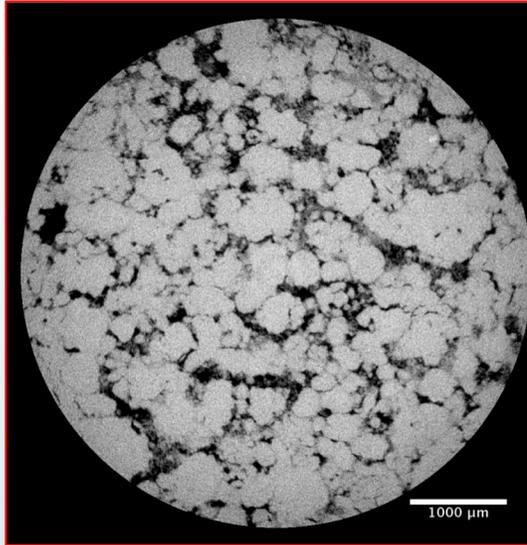Resistivity can be matched by joint inversion

However, the porosity reduction required for a velocity match is too high

Mao and Prasad
(in preparation)

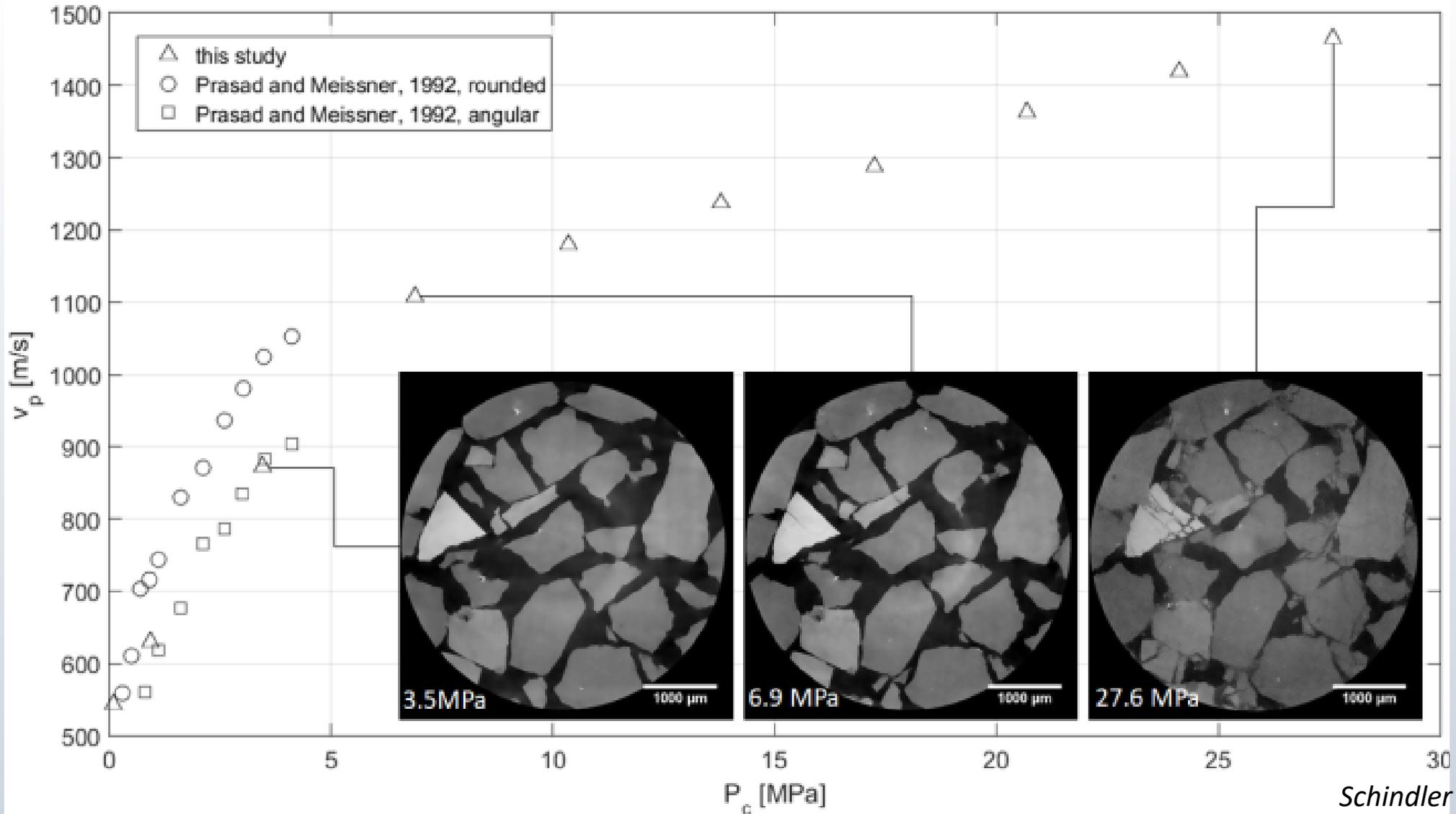# CYCLIC STRESS AND POROELASTIC PARAMETERS

HYSTERESIS IN ROCK PROPERTIES

Modulus measurements by Hasanov
CT Images by Schindler
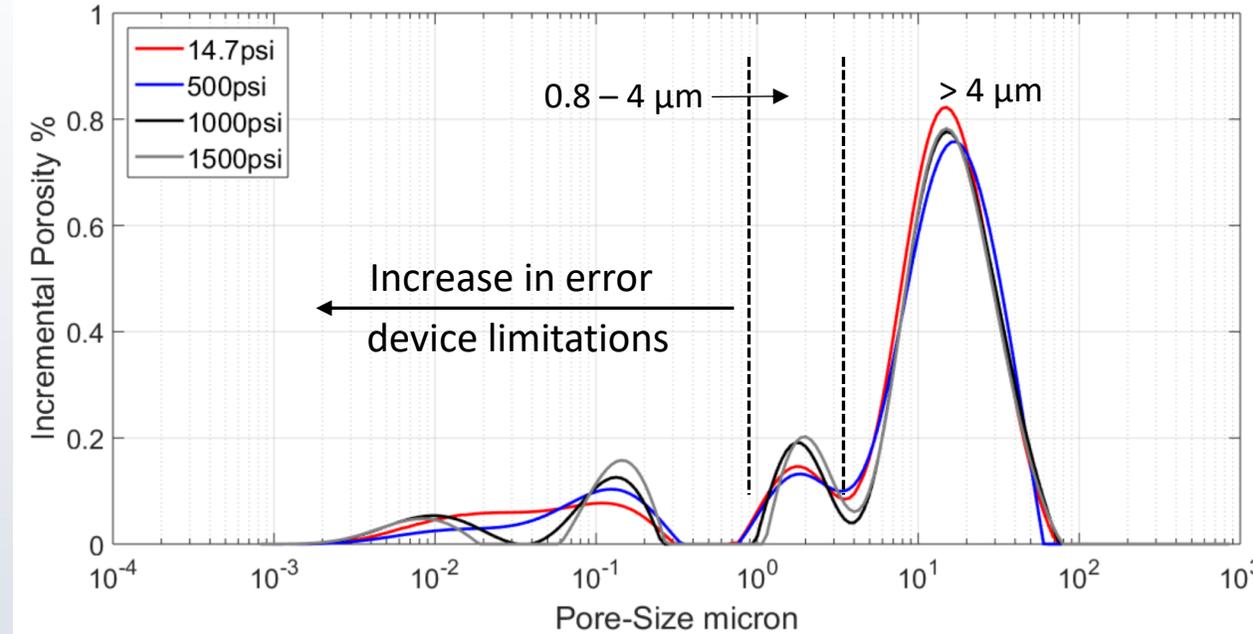*NMR T2 relaxations by Livo*

Grain Scale Changes
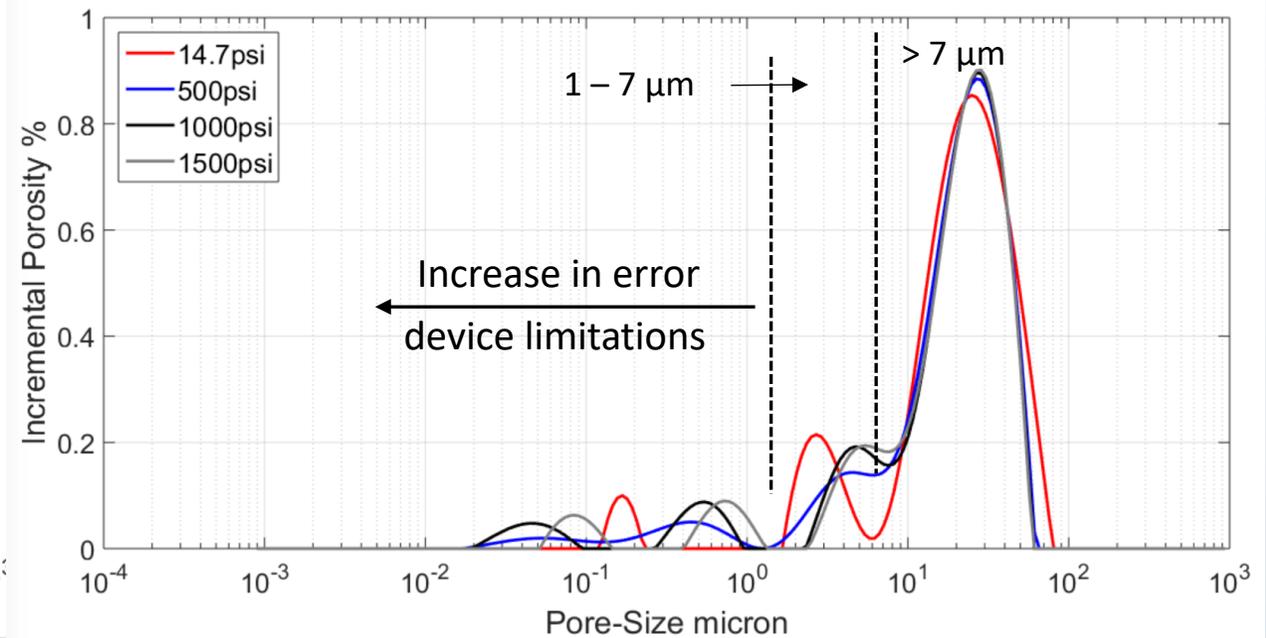

Schindler & Prasad, TBD

NMR T2 RELAXATIONS

NMR T2 Relaxation Changes with Pressure

BEREA SANDSTONE

SANDSTONE 1

surface relaxivity – 21.2 μm/s

pore sizes 0.8 – 4 μm, > 4 μm

surface relaxivity – 22.8 μm/s

pore sizes 1 – 7 μm, > 7 μm

Guliyev, 2018

Compressibility of Pore Clusters

Berea: 0.8 – 3 μm

Sandstone: 1 – 8 μm

Berea: > 3 μm
Sandstone 1: > 10 μm
Sandstone 3: > 1 μm

Sandstone 2
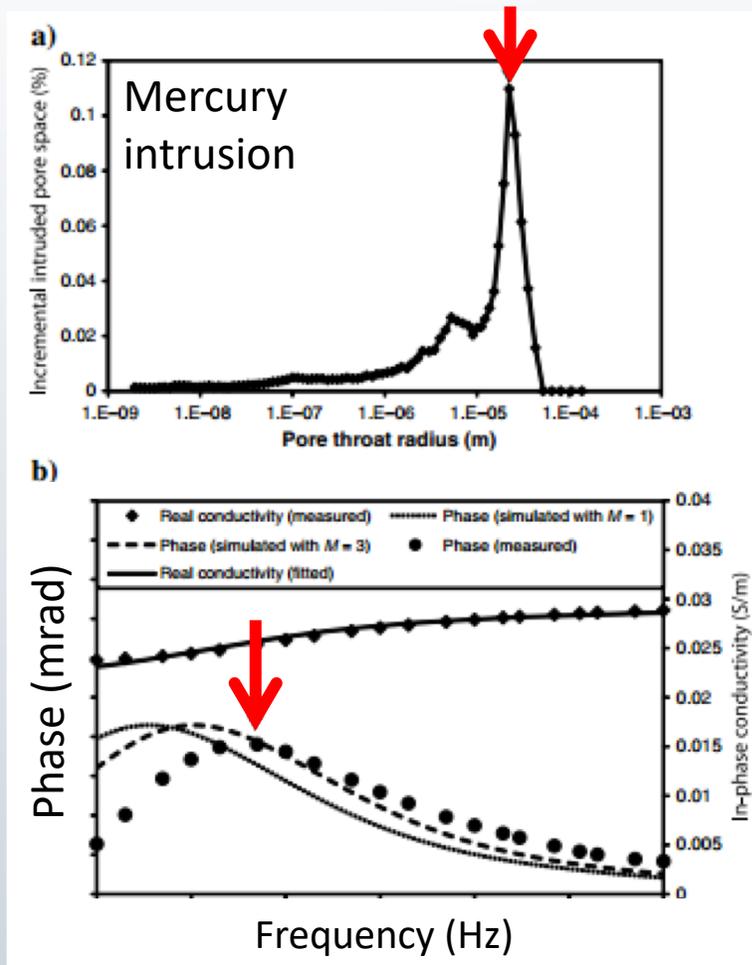1 – 3 μm

Sandstone 2
> 3 μm
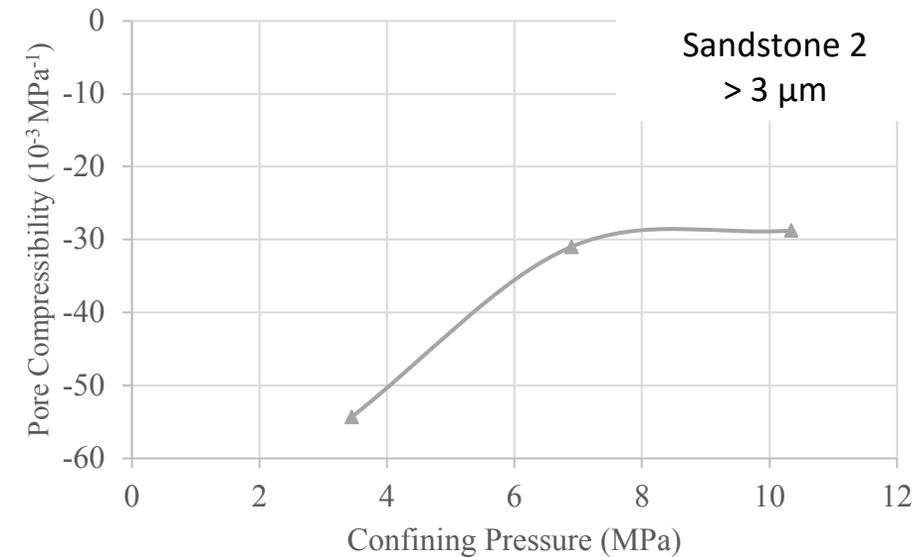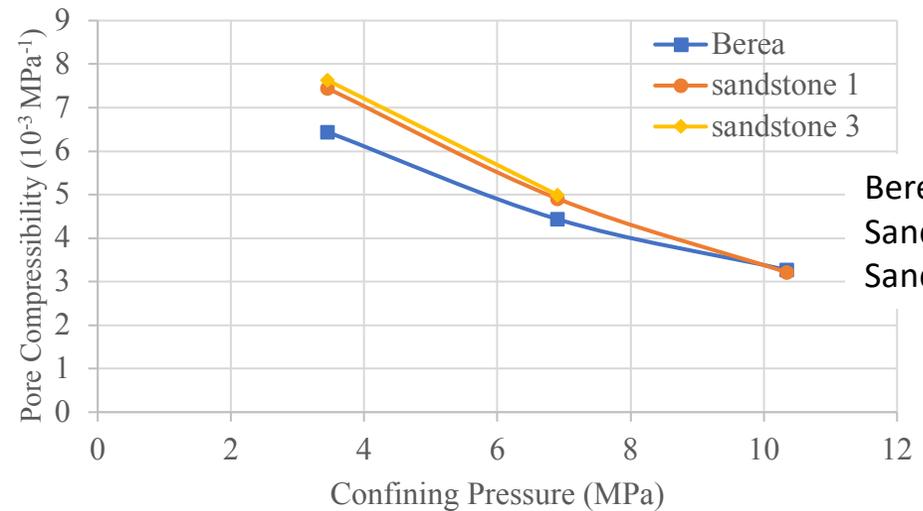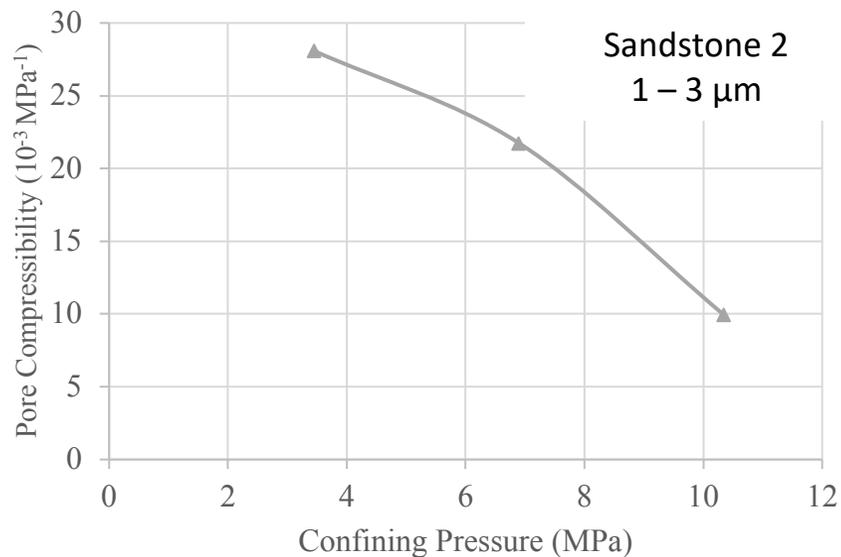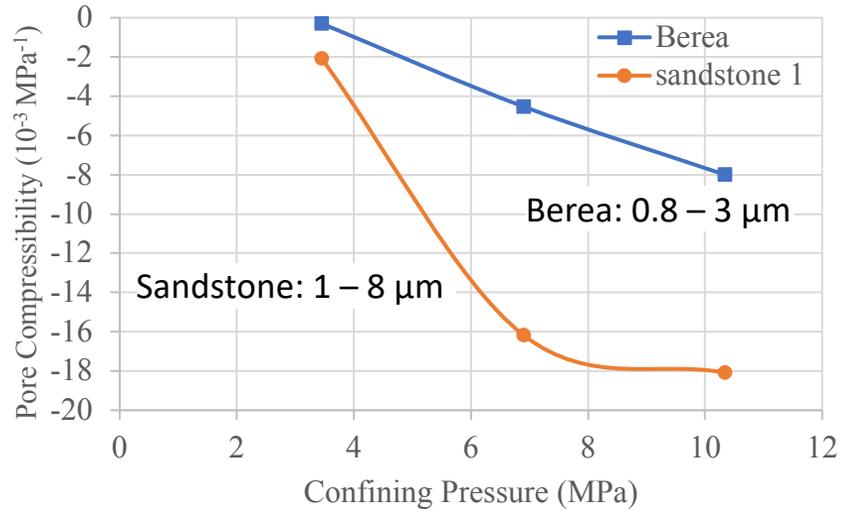
Guliyev, 2018

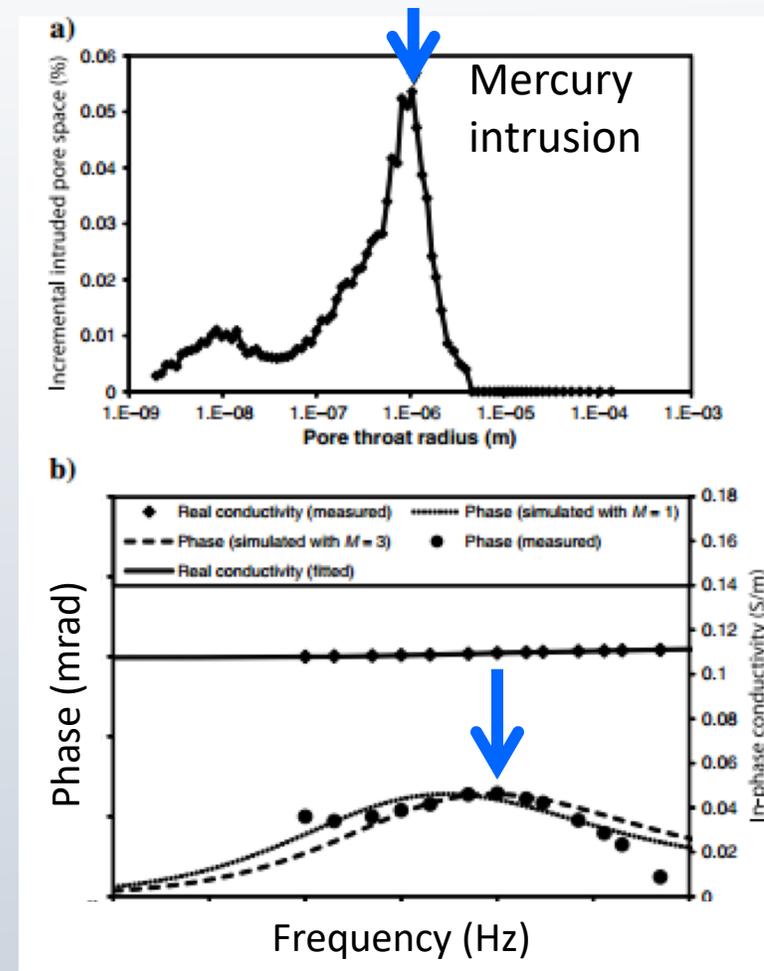# Benefit of Combining Complex Conductivity with Velocity

Larger pores → lower characteristic frequency;
Smaller pores → higher characteristic frequency:
PSD changes with pressure should be reflected in frequency shift for σ''

Larger pore sizes

Smaller pore sizes
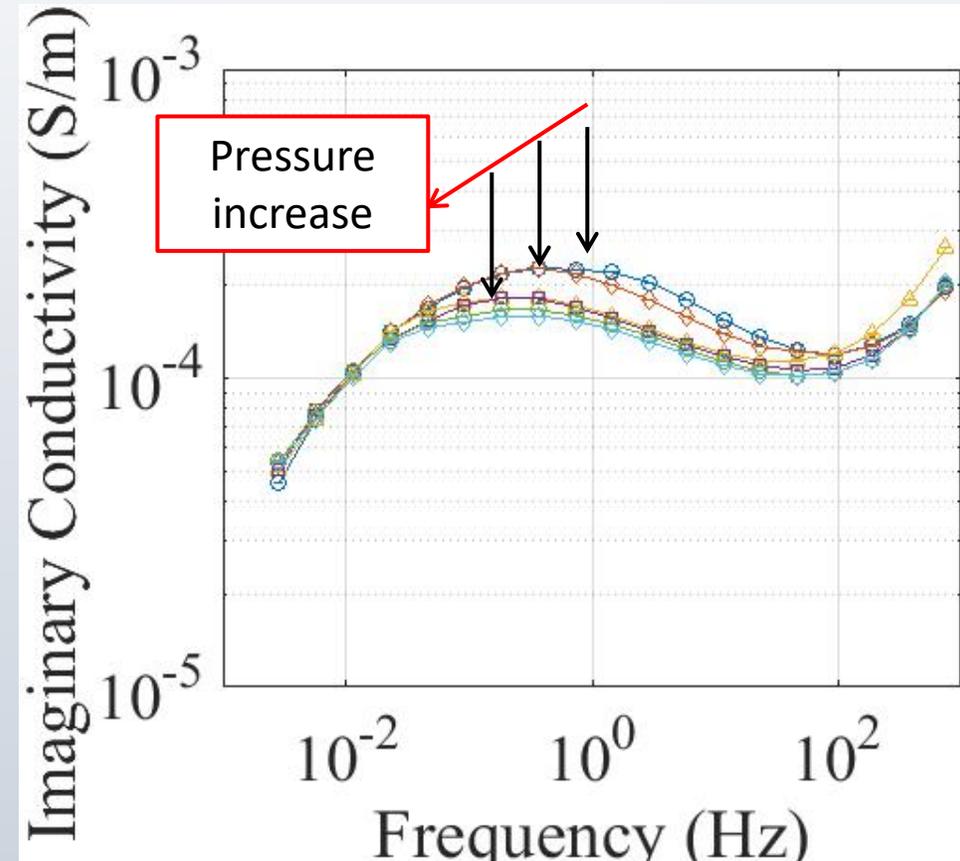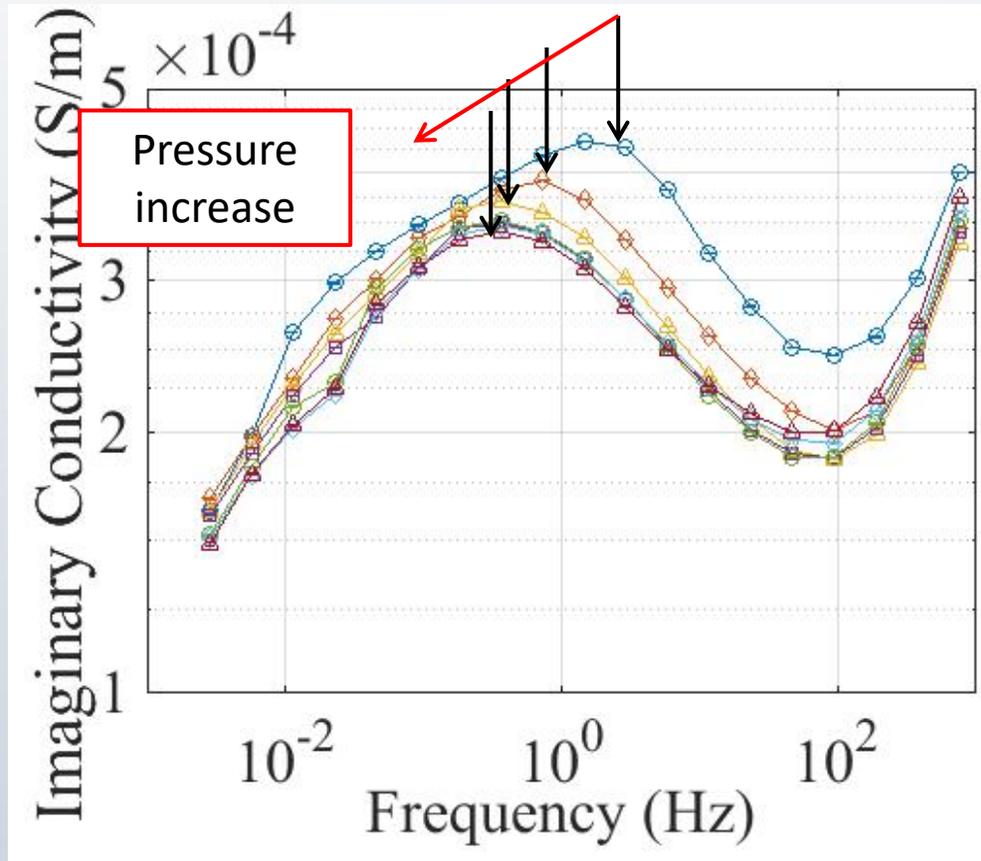
Lower frequency

Higher frequency

Niu & Revil, 2016

Results – Imaginary Conductivity

Nugget Sandstone

ϕ (%)	15.0
k (mD)	125
ρ_g (g/cc)	2.65
σ_f (S/m)	0.13

Berea Sandstone

ϕ (%)	20.3
k (mD)	216
ρ_g (g/cc)	2.63
σ_f (S/m)	0.12

Pressure increase

Pressure increase

Mapeli, 2017

MCT IMAGING & ACOUSTIC MEASUREMENTS

Imaging Core Scale Changes

Ultrasound laboratory data give us bulk elastic properties. We still need to resolve their sensitivity to millimeter scale changes in:

- Texture, heterogeneity, fluid saturation and flow

- Stress, grain damage and grain rearrangements

Can time lapse monitoring be improved by high resolution imaging?
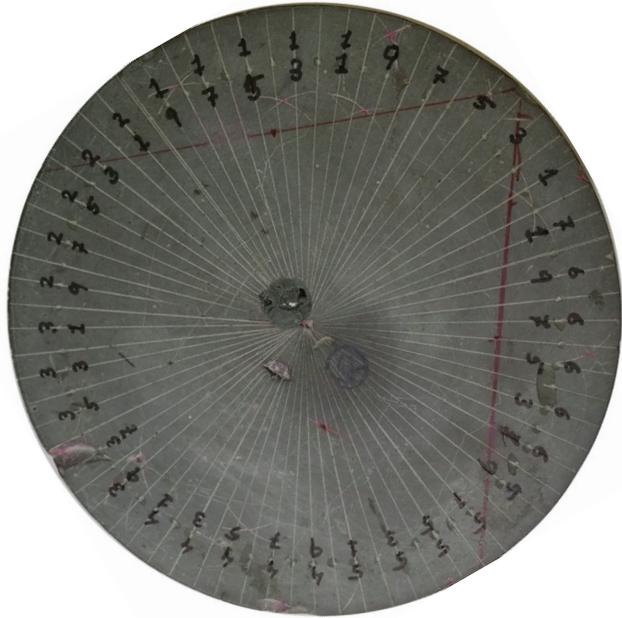
Seismic FWI imaging

Travel-time
Tomography

How accurate are these images (ground truth)?
Reconstruct bulk velocities given the impedance changes?
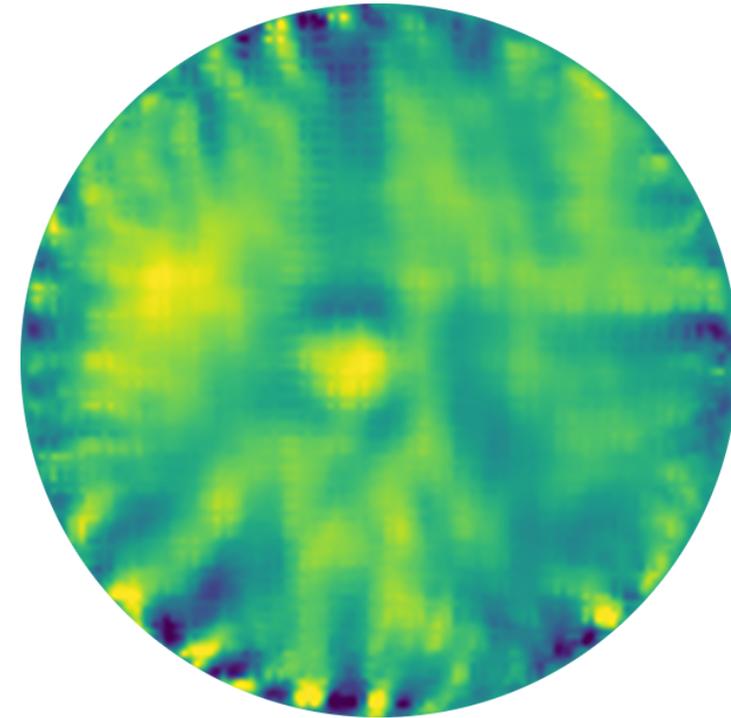
FWI

Virieux & Operto. 2009

Imaging by FWI

Optical Image

FWI Image (initial pass)

FWI Image (not-final pass)

Forghani-Arani et al., 2017

In Summary

- It is critical to make simultaneous multi-physics measurements to understand seismic and electrical properties

- Pore cluster compliance helps to better explain pressure dependent changes

- Laboratory scale experiments are needed to calibrate and provide ground truth for FWI (Full Waveform Inversion) seismic images for physical properties
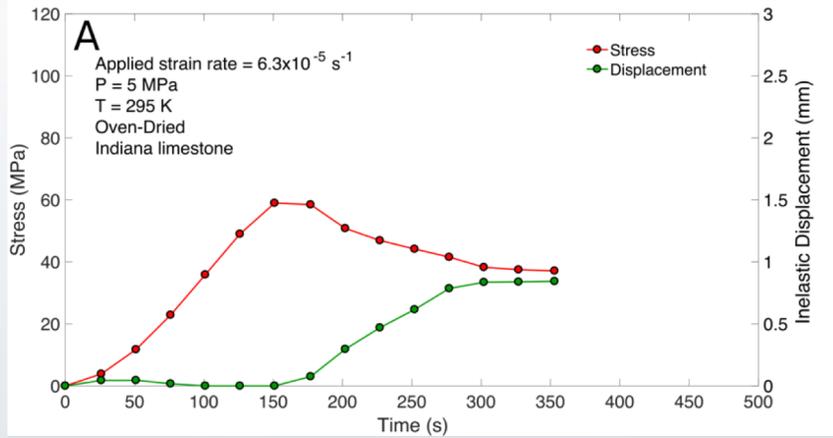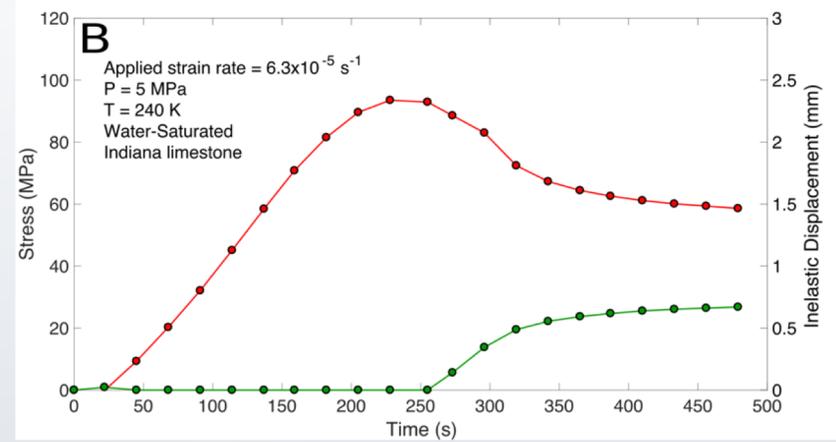
BEYOND: ICE AS A PORE-FILLING PHASE

Application to ISRU (In Situ Resource Utilization)
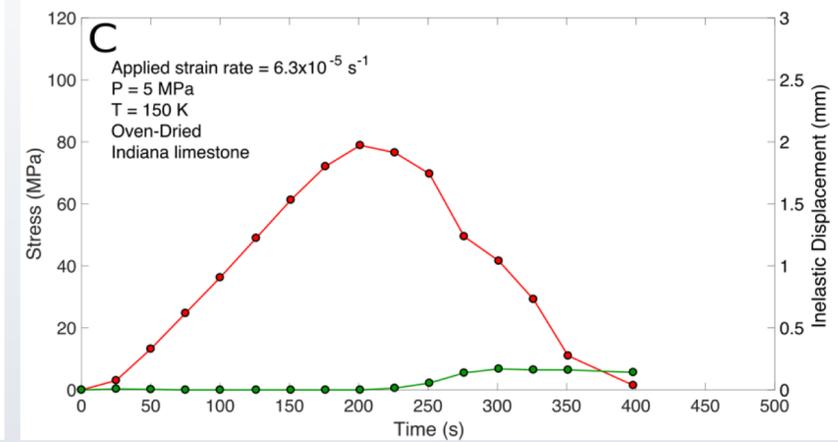
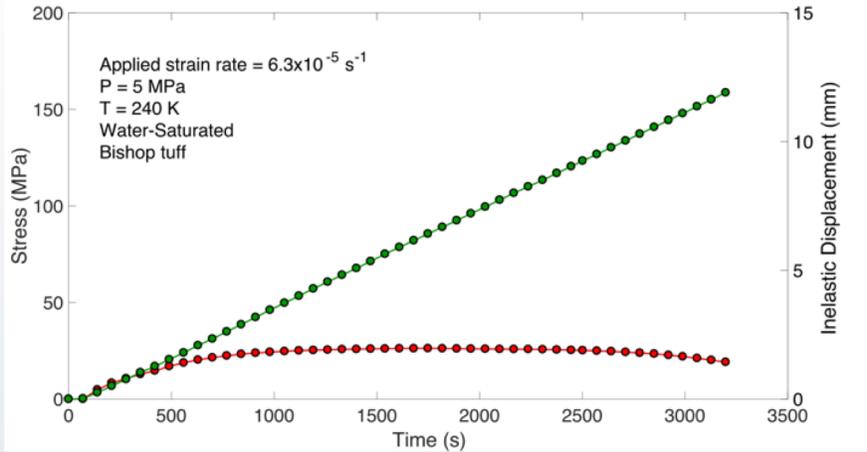# Cryogenic Deformation of Saturated Limestone

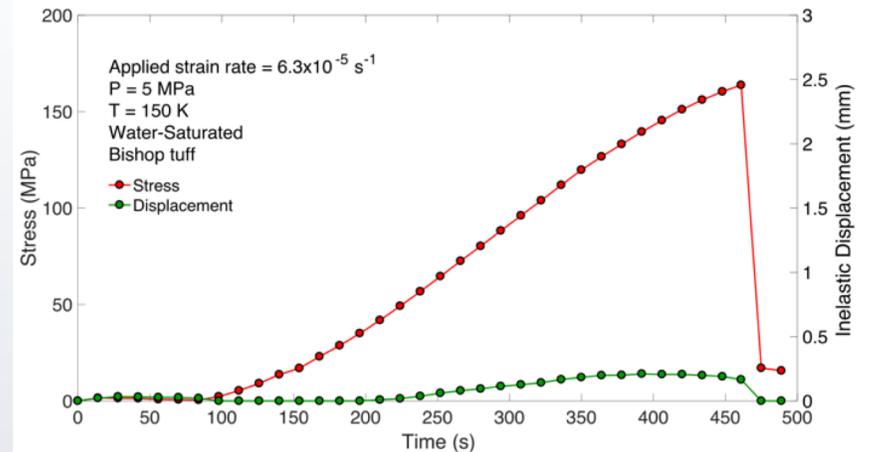295 K

240 K

150 K

Atkinson et al., 2018

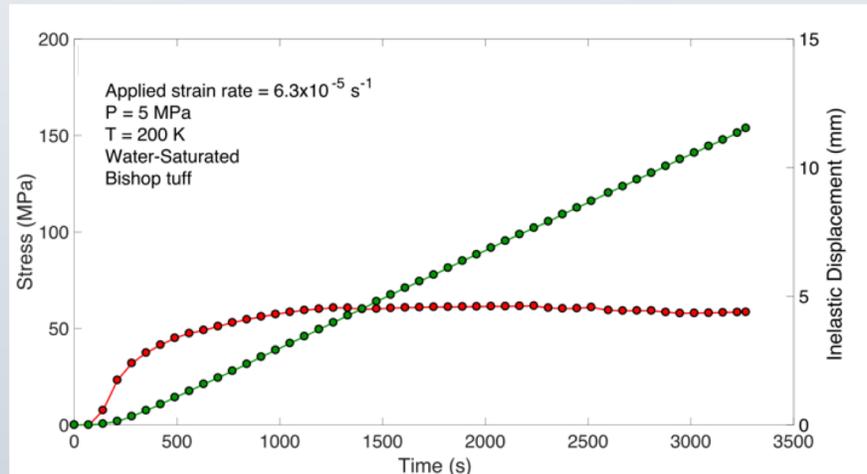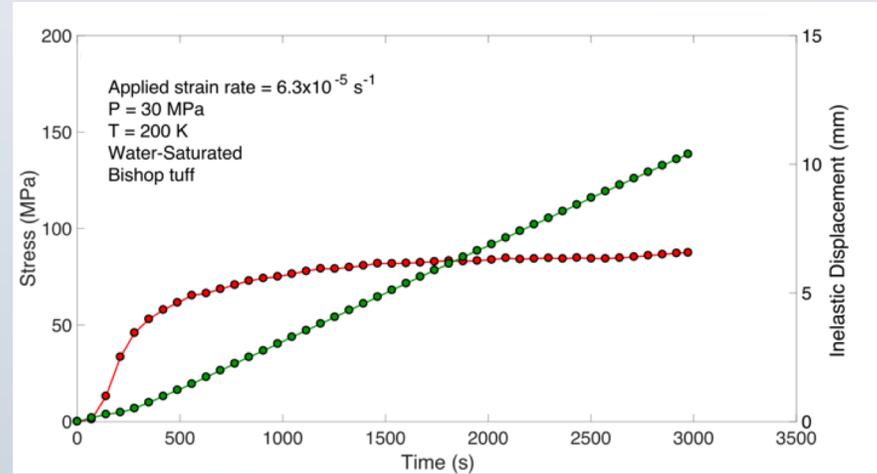# Cryogenic Deformation of Saturated Tuff
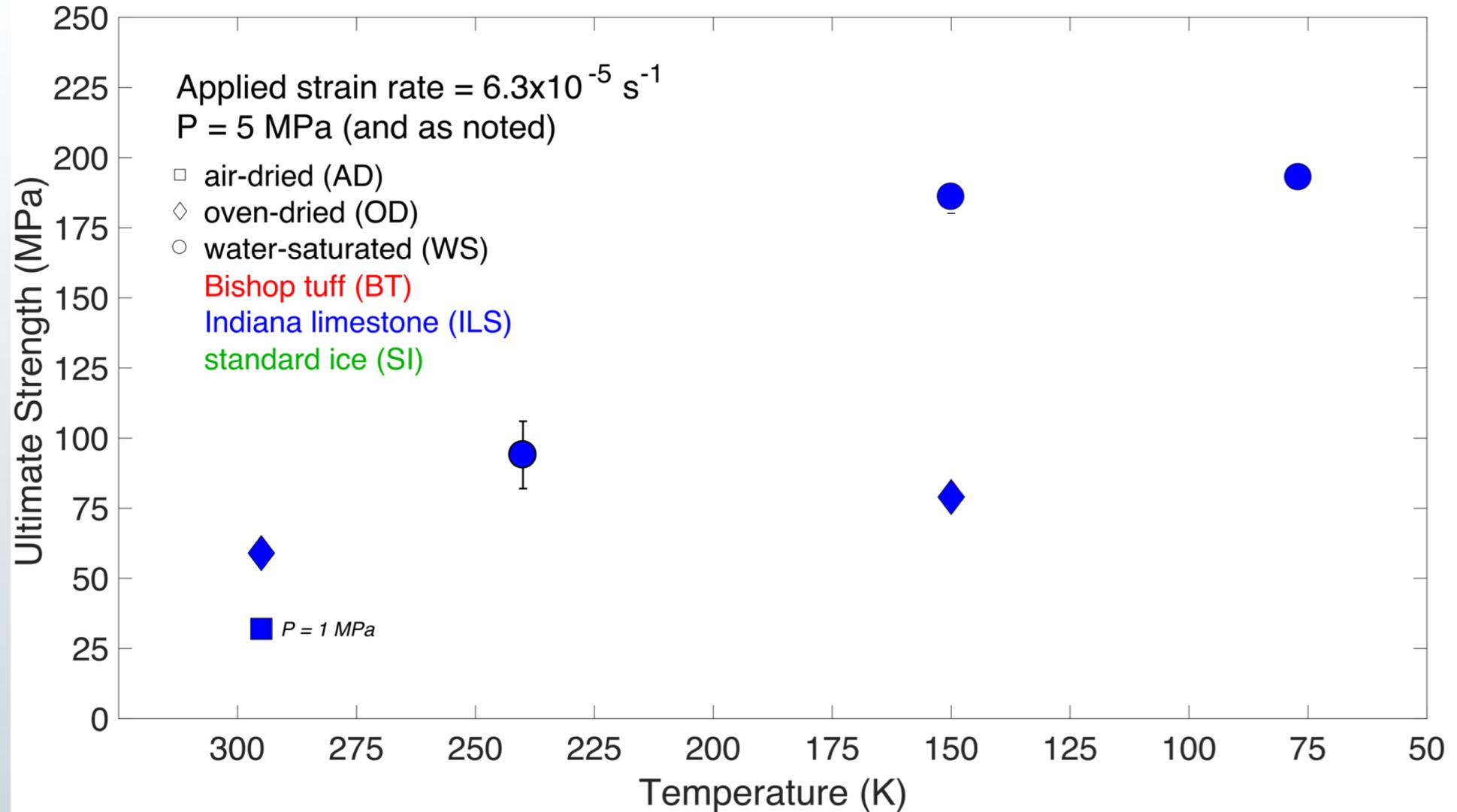
240 K

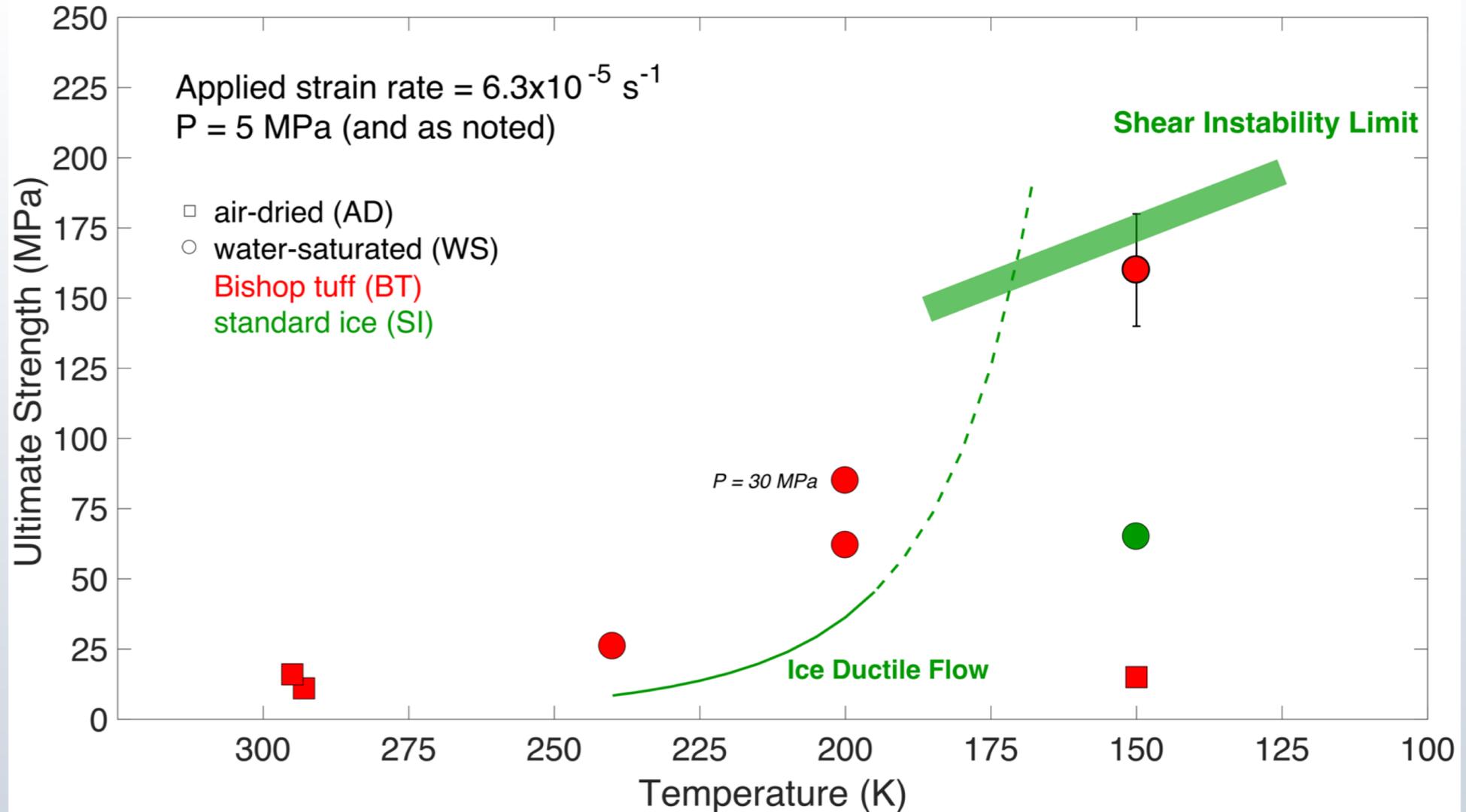
150 K

200 K

200 K & P_c = 30 MPa

Atkinson et al., 2018

Strength & Cryogenic Temperature

Atkinson et al., 2018

Controlling Effect of Ice

TAKK!

Questions?