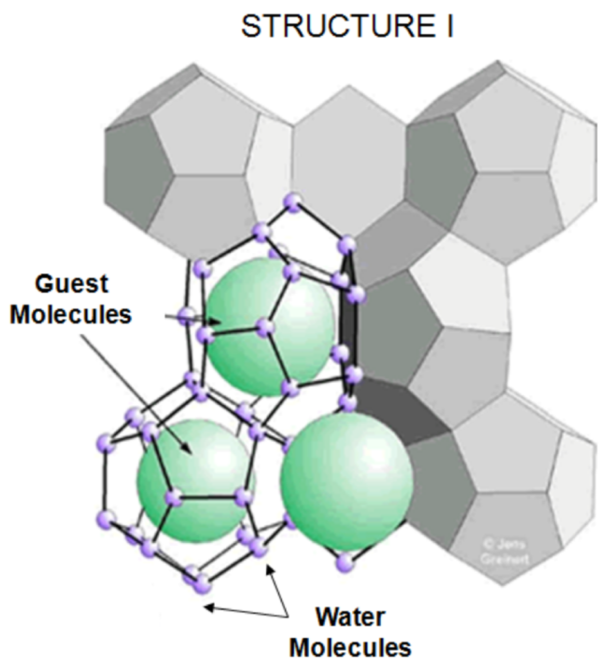
Laboratory measurements on THF-hydrate bearing porous media

ROSE Meeting
Trondheim, Norway

Mandy Schindler, Manika Prasad

April 25, 2016

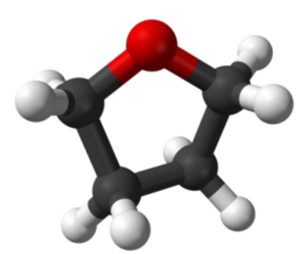
Introduction



- **Low Temperature, High Pressure**

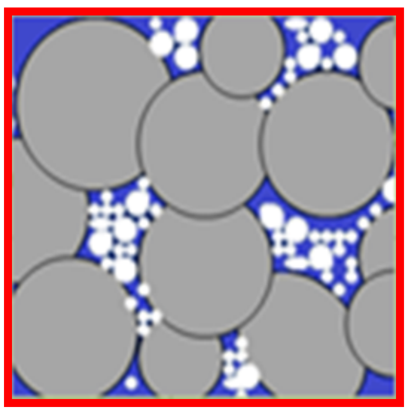
- Arctic permafrost
- Marine sediments (> 500m deep)

- **Availability of methane and water**
- **Formation: gas dissolved in water or free gas phase**
- **For laboratory experiments: tetrahydrofuran hydrate**

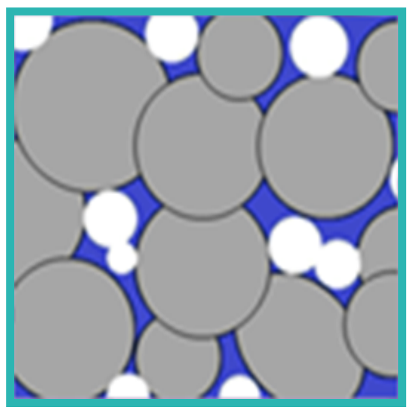


Pore-Scale Hydrate Distribution

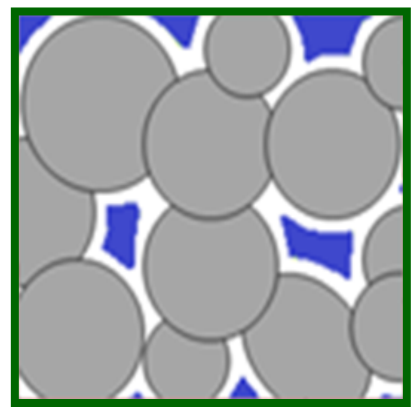
Pore Filling



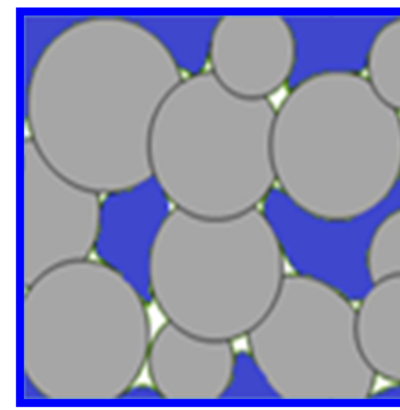
Sediment Frame



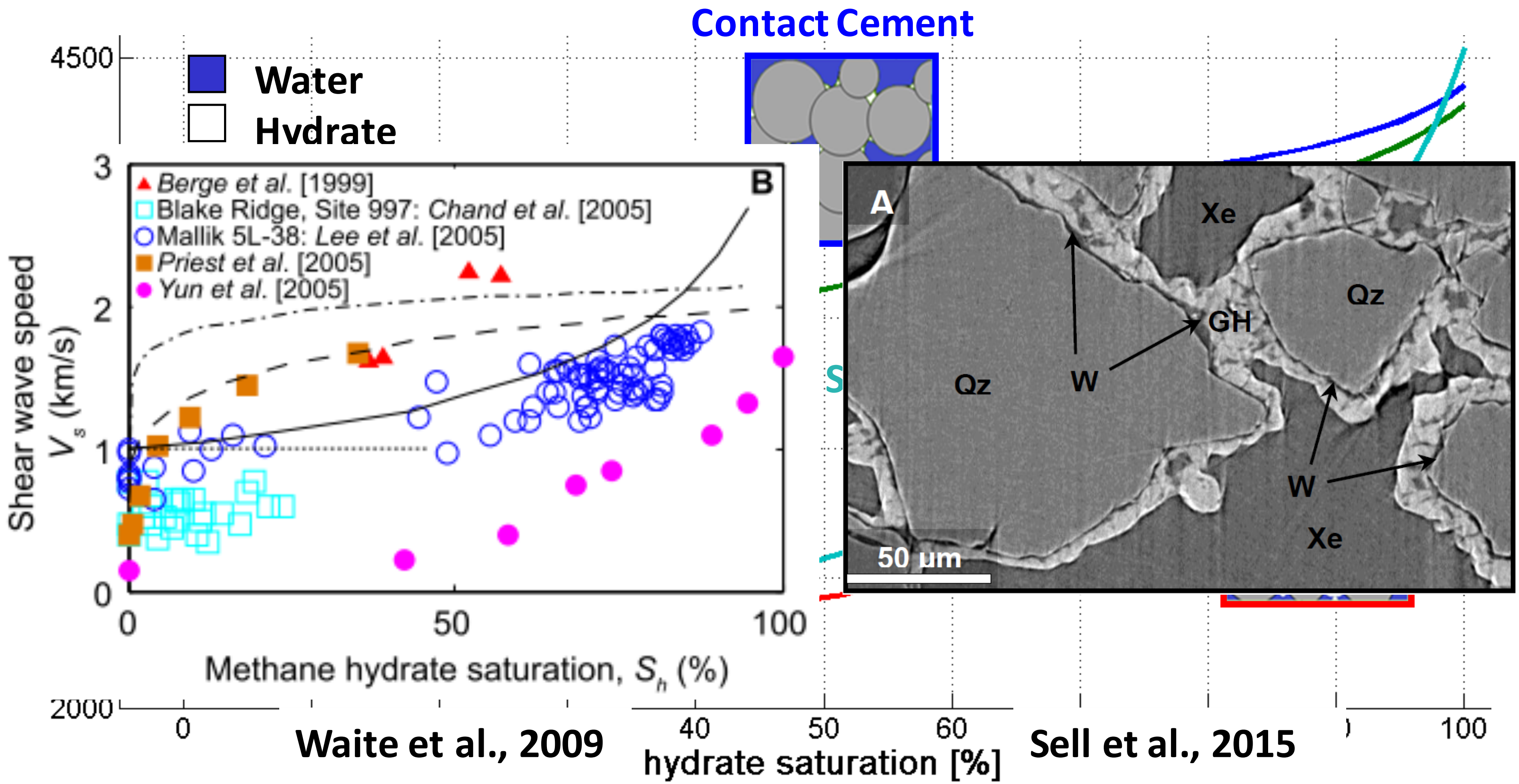
Envelope Cement



Contact Cement



Rock Physics Models



Waite et al., 2009

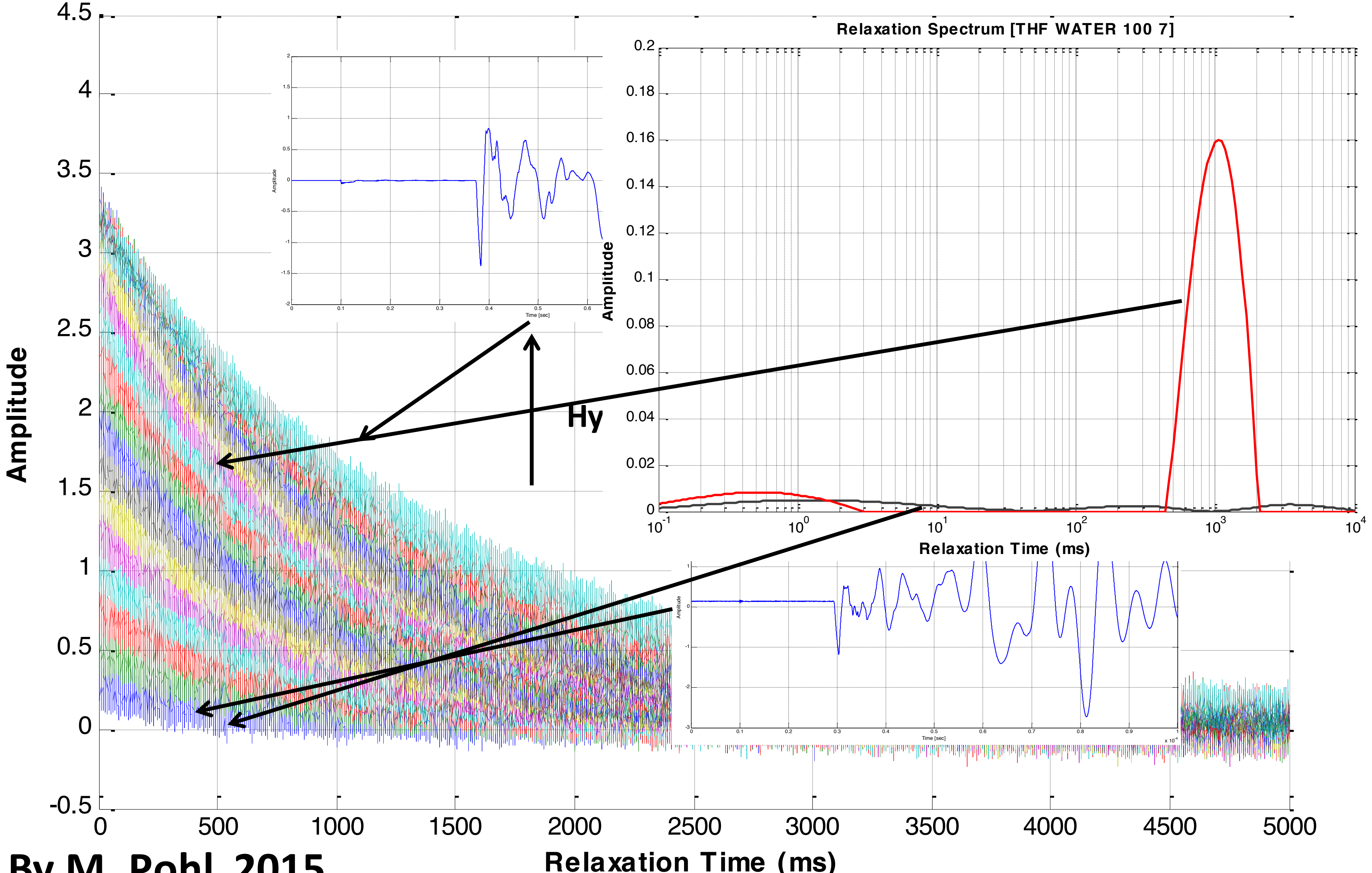
Sell et al., 2015

Effective medium model by Ecker et al., 1998, Helgerud et al.,1999 based on work by Dvorkin et al., 1994

3rd International Workshop on Rock Physics, Perth April 2015

Relaxation Time for 100 % THF Hydrate

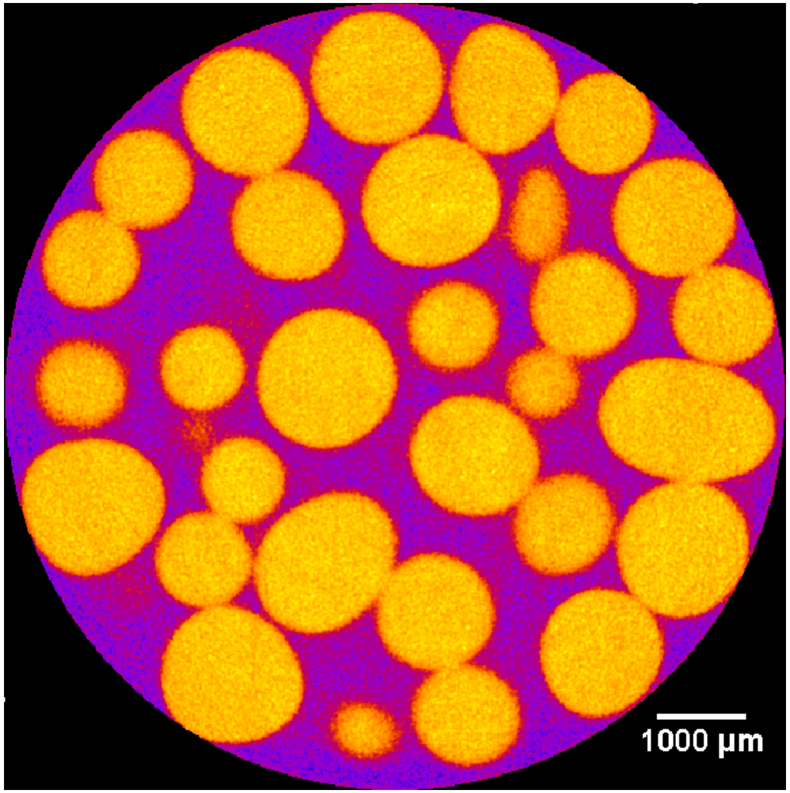
RAW DATA



By M. Pohl, 2015

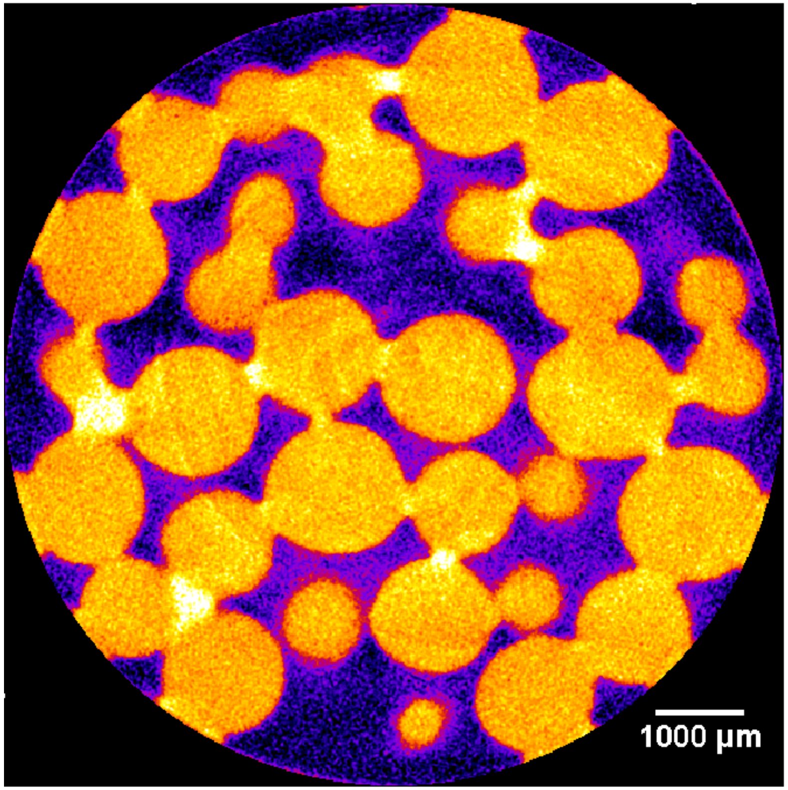
Micro CT Imaging

$BaCl_2$: 6wt%



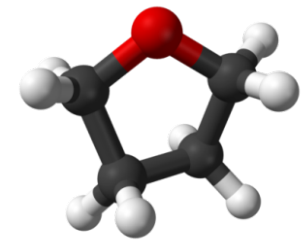
Room temperature

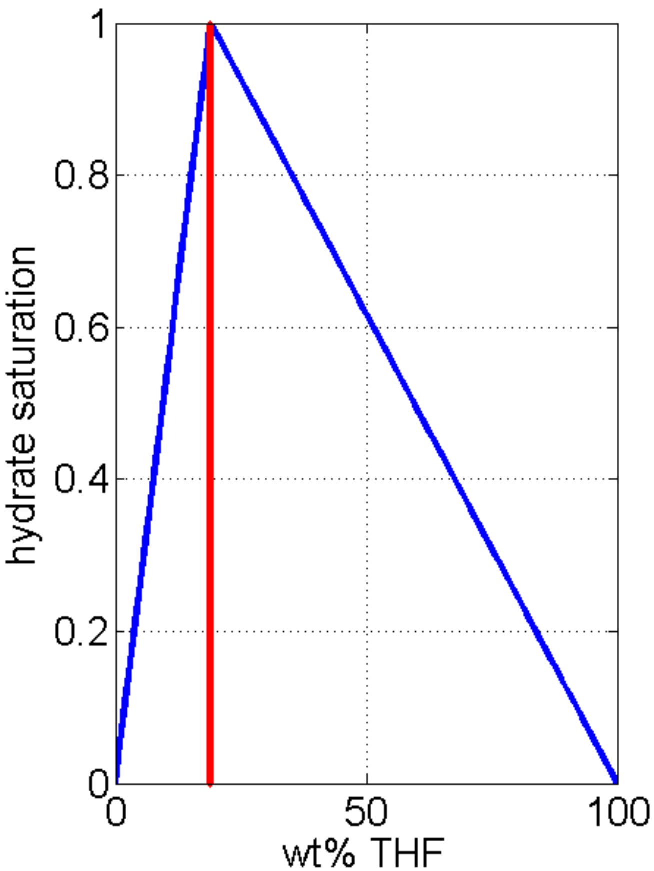
$BaCl_2$: 23wt%

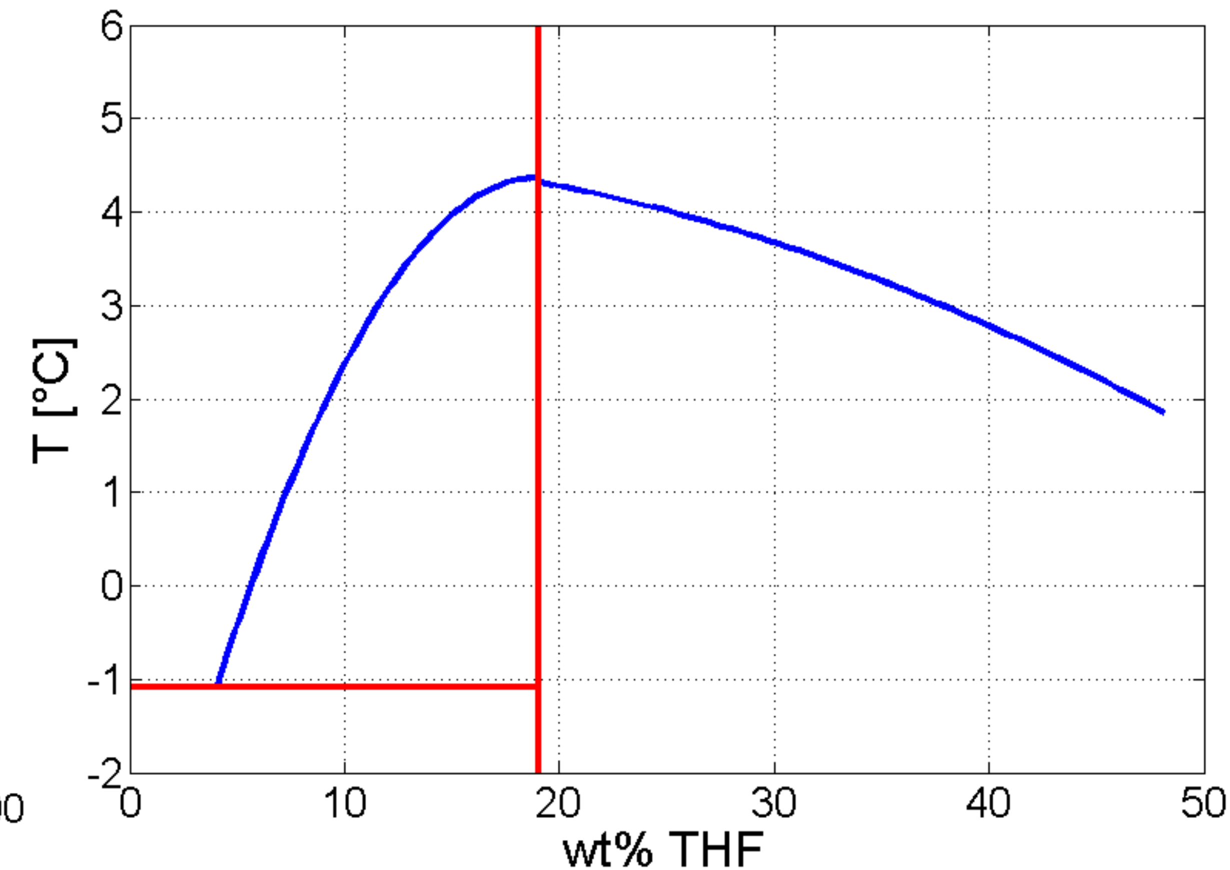


1°C
80% THF hydrate saturation

Tetrahydrofuran (THF) Hydrate

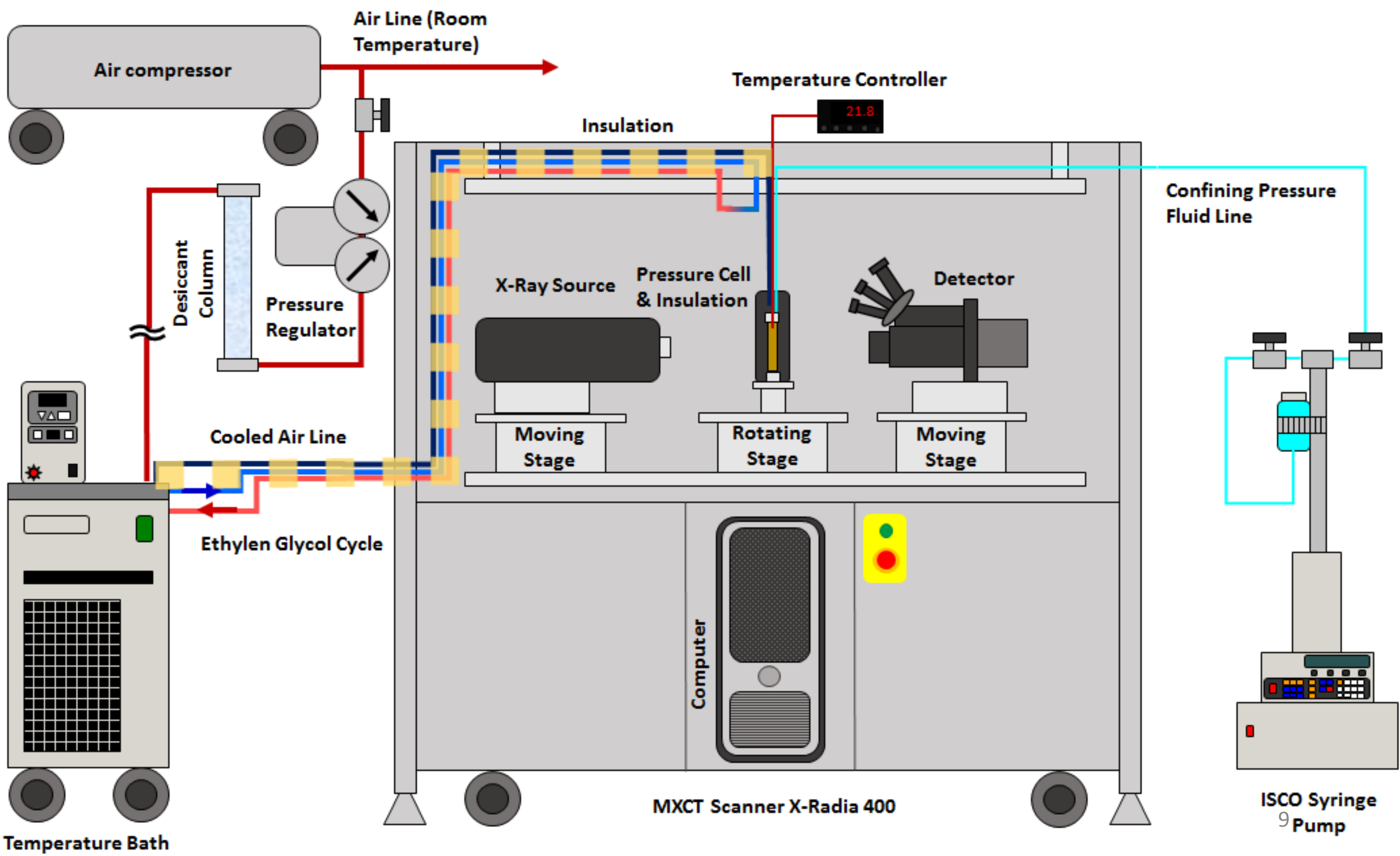




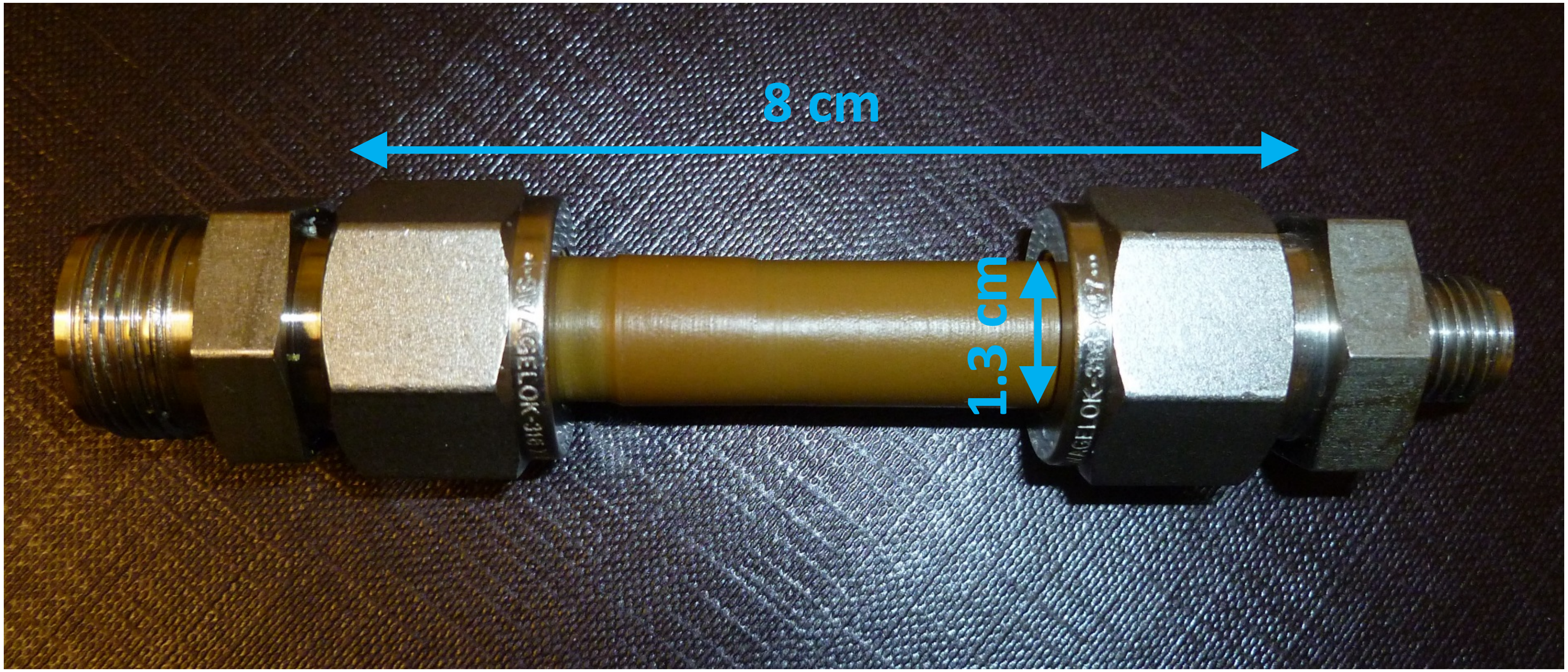


after Makino et al., 2005

Micro CT Experimental Setup



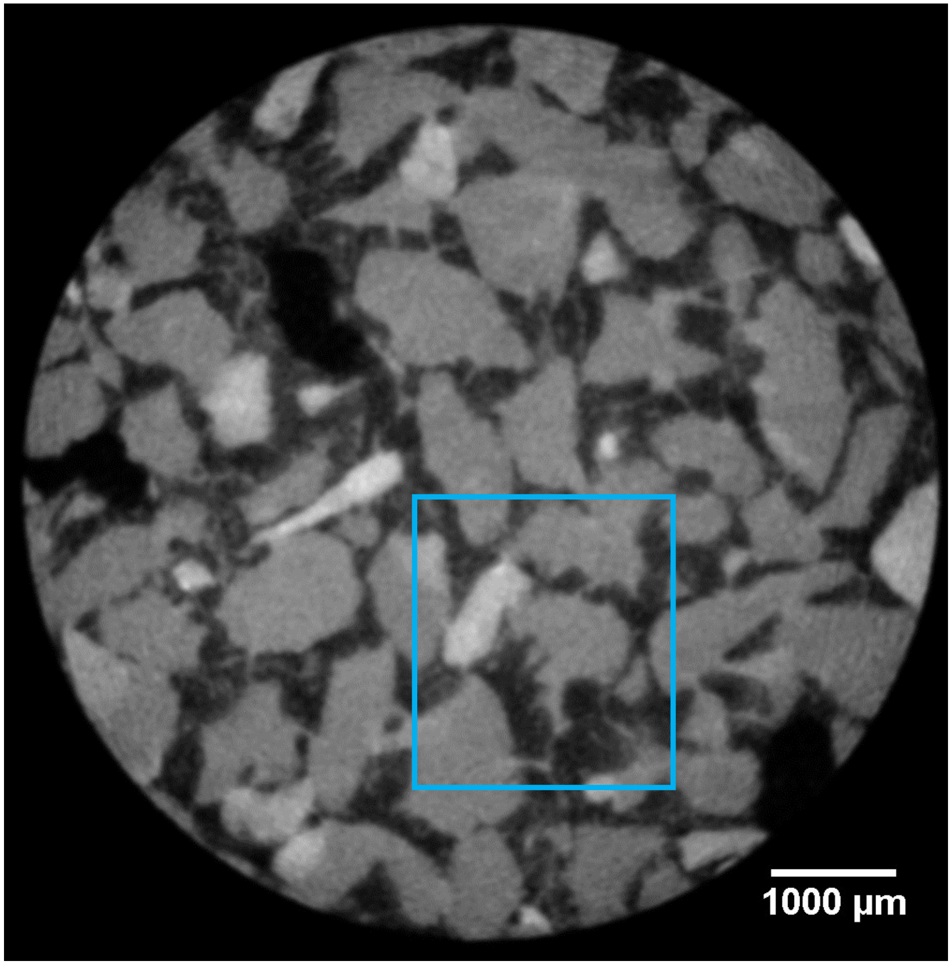
Micro CT Pressure Vessel



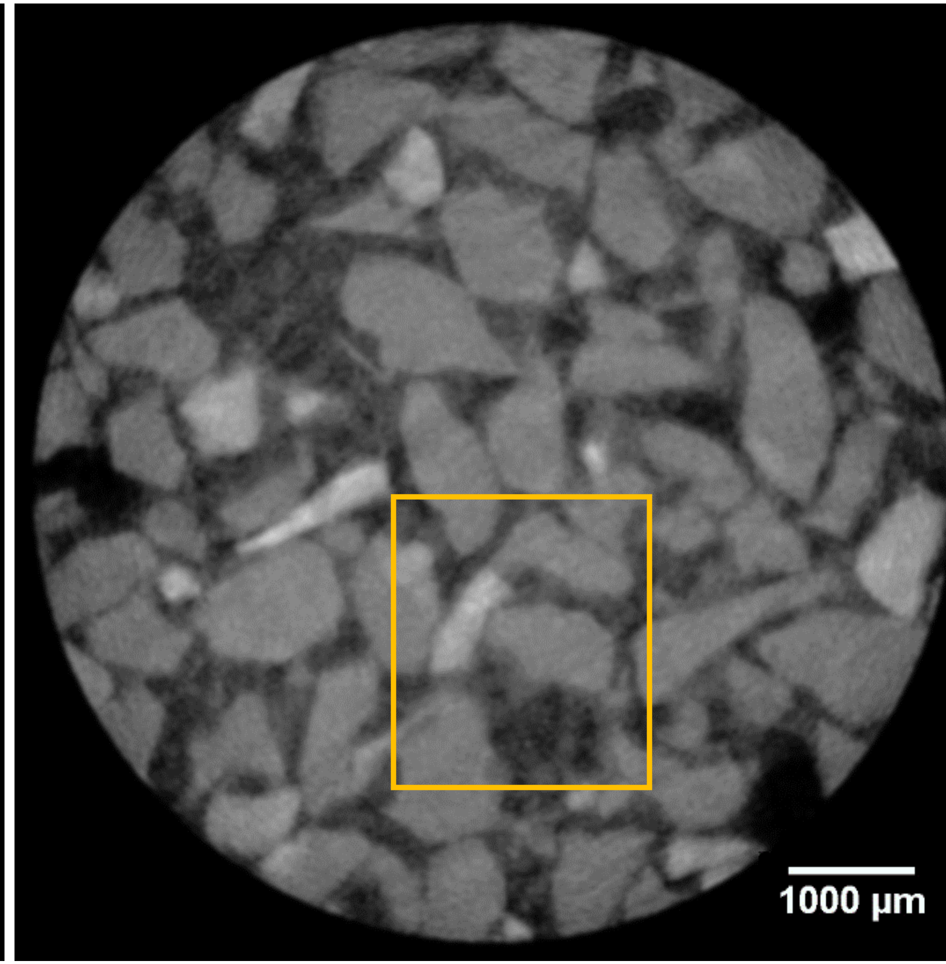
- Torlon pressure vessel (up to 5000 psi – 34.5 MPa)
- inner diameter: 8 mm, outer diameter: 12.7 mm (0.5 inches)
- Quartz sand (ø grain size: 1000 µm) and clay (bentonite) as host sediments
- THF and water as hydrate-forming components
- Barium chloride added for density contrast (~12 wt%)
- Cooling ~ 8 hours
- Resolution: 10 microns

Quartz With S_h=80%

With Hydrate

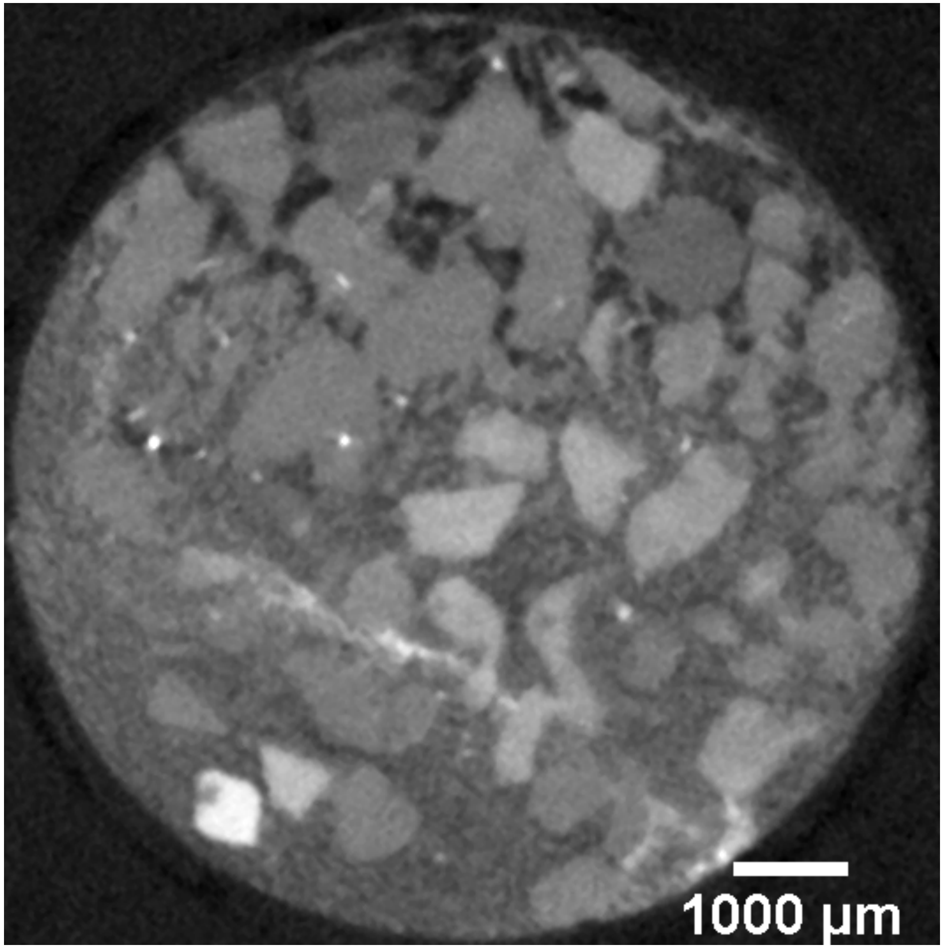


Without Hydrate

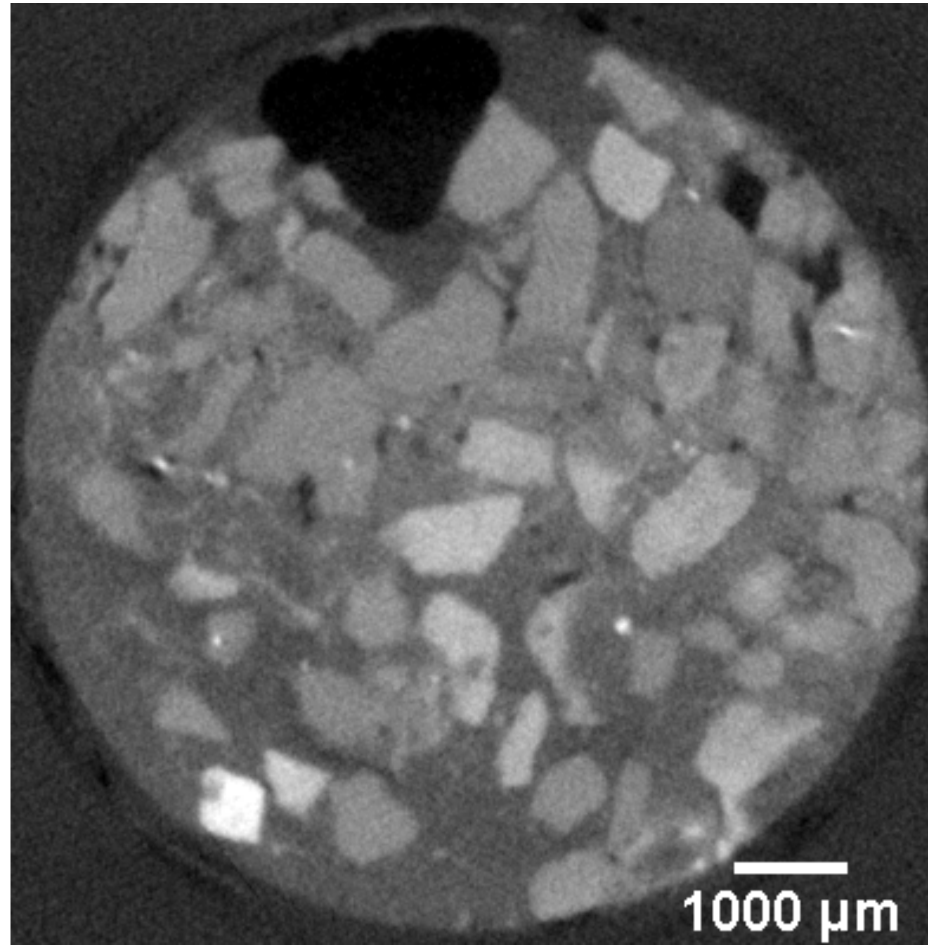


Quartz and Clay With S_h=80%

With Hydrate

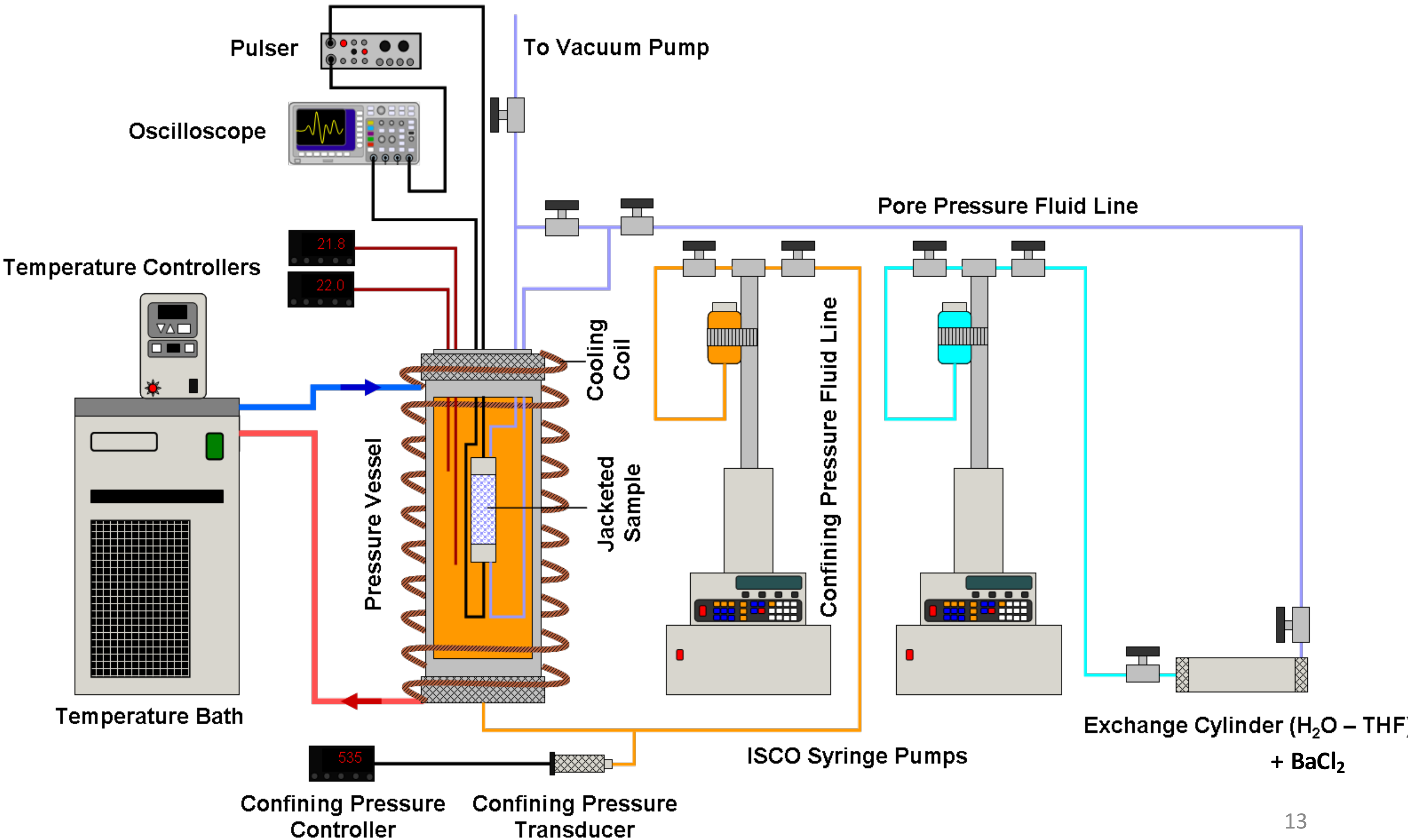


Without Hydrate

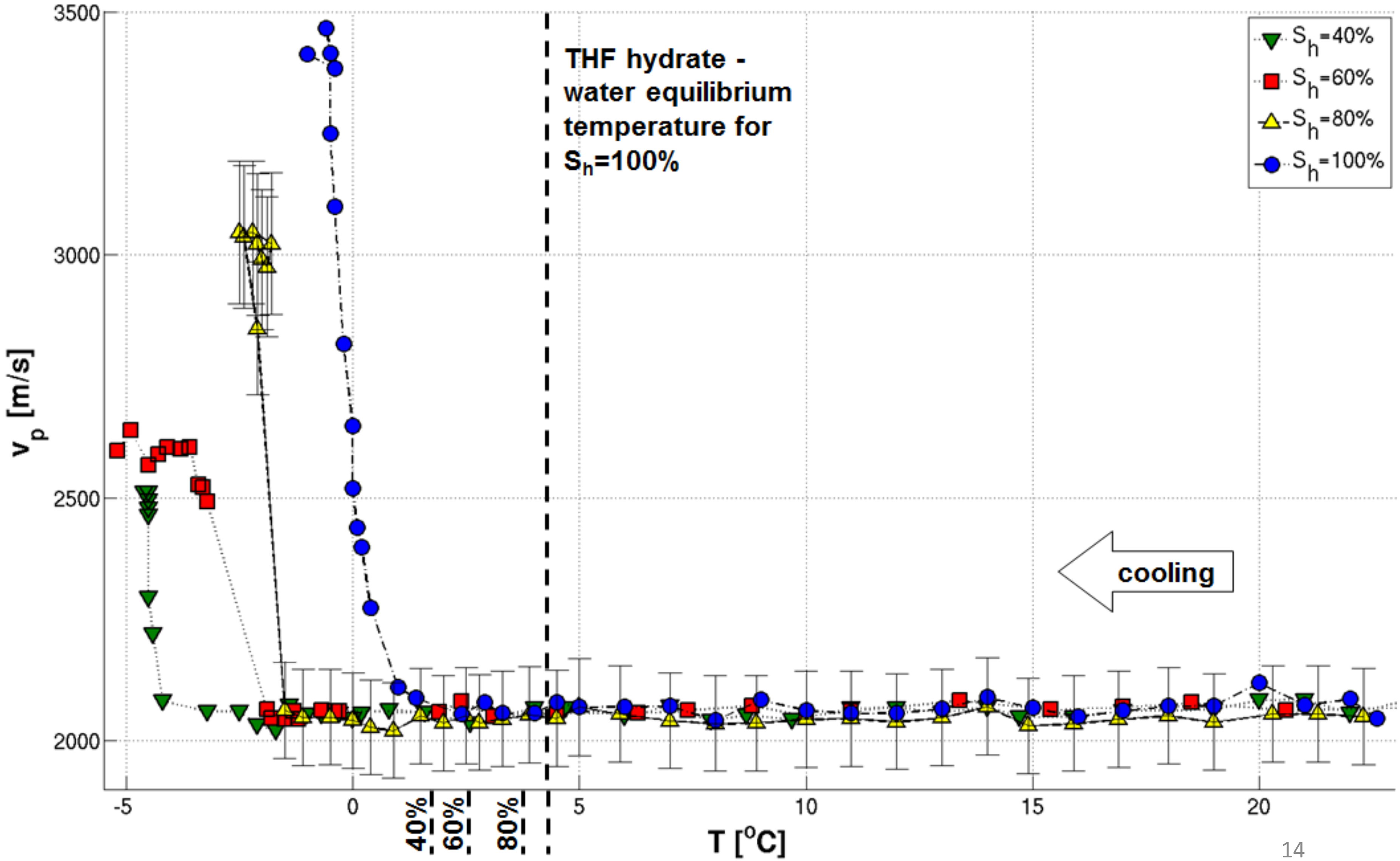


Heterogeneity in hydrate and clay distribution
Clay moved by hydrate

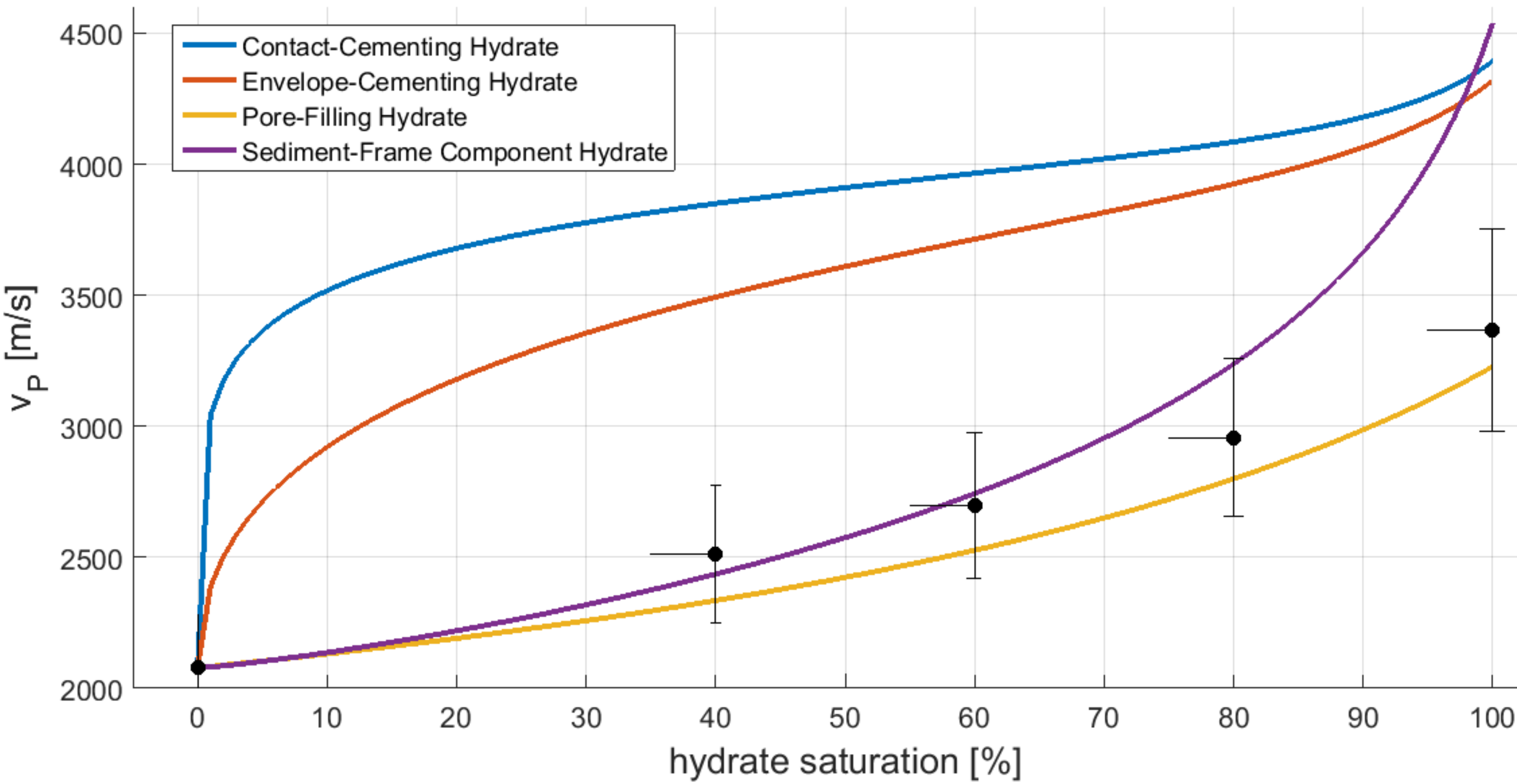
Ultrasonic Velocity Measurements



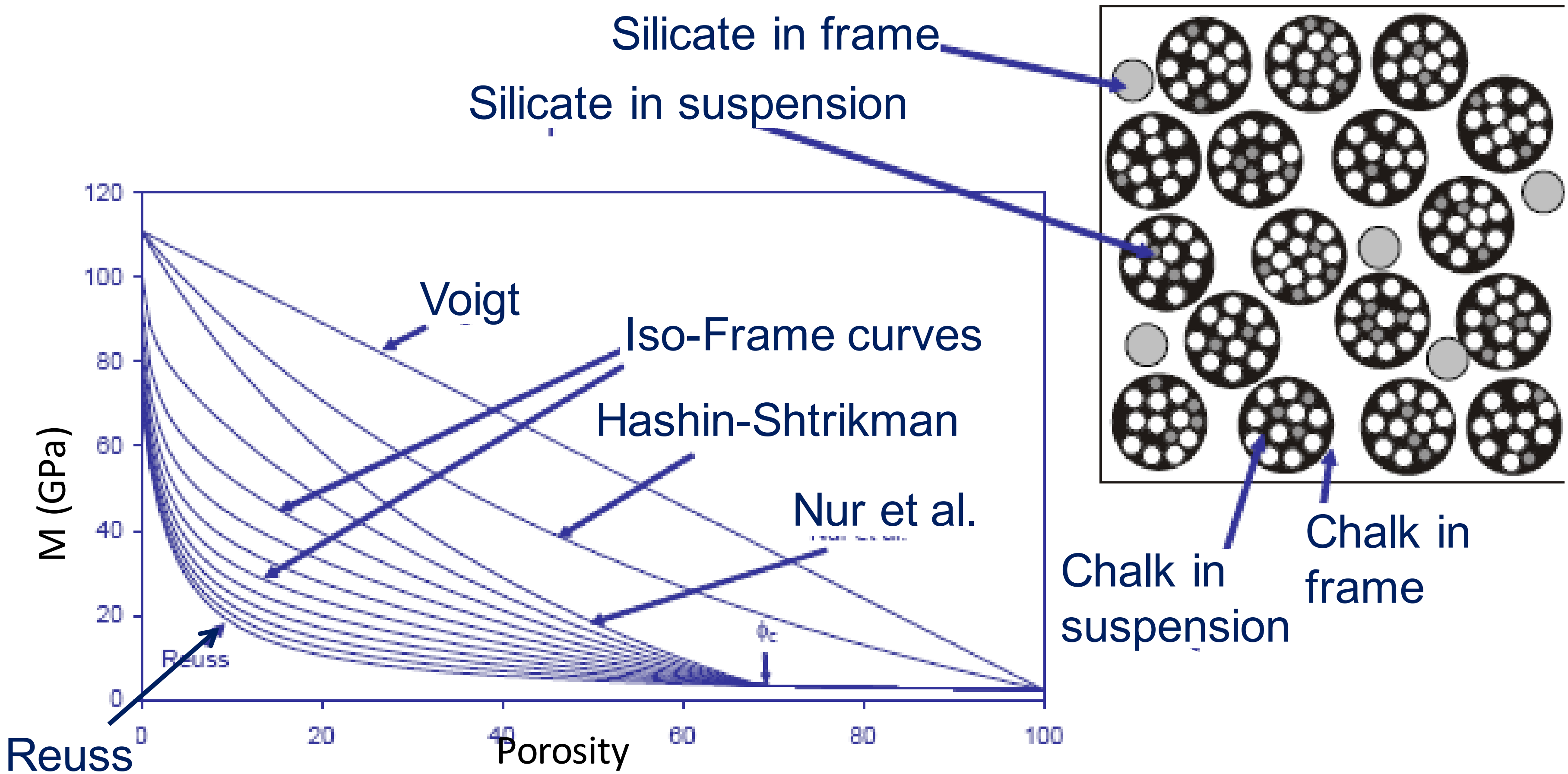
Velocities for Different Hydrate Saturations



Effective Medium Models



Iso-frame Model



Iso-frame fraction IF α 1/Φ

And affects elastic moduli and velocity

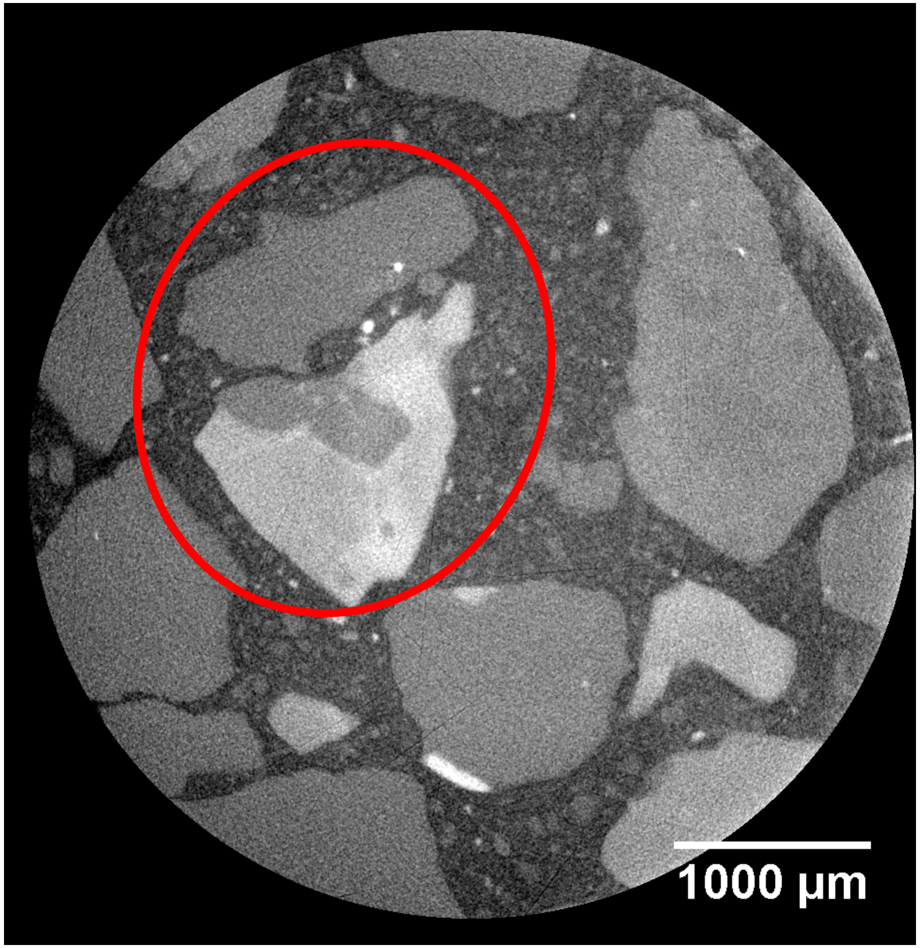
Fabricius et al., 2004

Conclusions

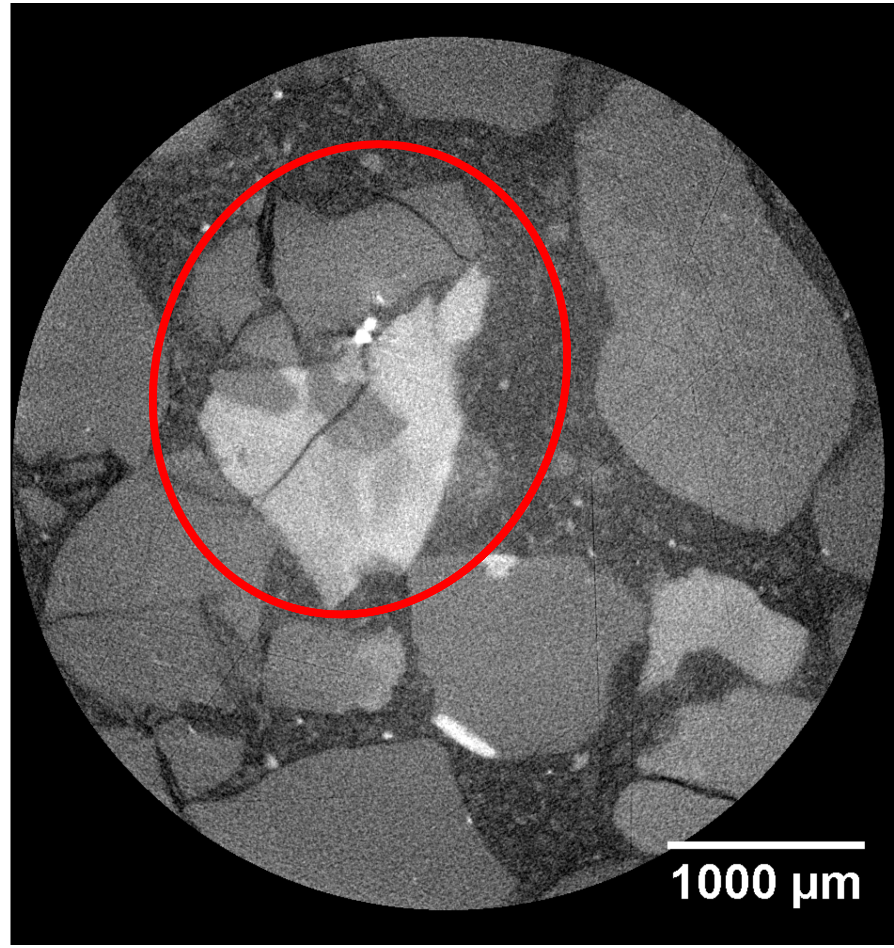
- Significant improvement of µCT image quality and resolution → use different host sediments
- Hydrate distribution does not confirm one model
- Mixing of effective medium models: partially load bearing, partially pore filling
- Clay causes heterogeneous hydrate saturation → clay moved during hydrate formation

- Link changes in elastic properties (from US velocities) to their cause on the pore scale (from µCT imaging)

μCT Imaging Under Confining Pressure



Atmospheric pressure



2000 psi (13.8 MPa)

Acknowledgements

- Department of Energy
  grant number: DE-FE 0009963

- Fellow rock abusers: Azar Hasanov, Hanna Flamme, Kurt Livo

- Dr. Mike Batzle

CENTER FOR ROCK ABUSE
Squeezing Rocks since 1994

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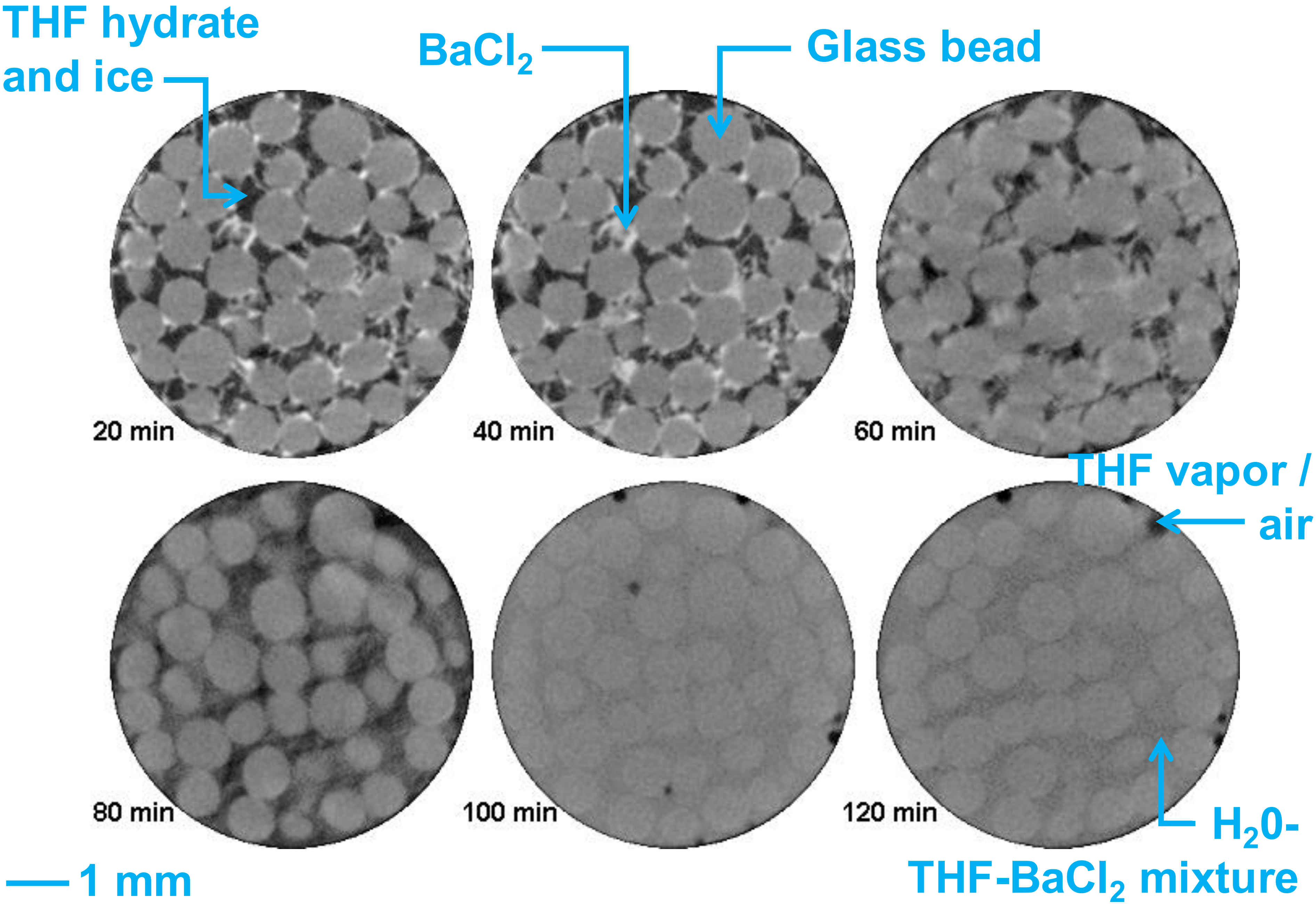
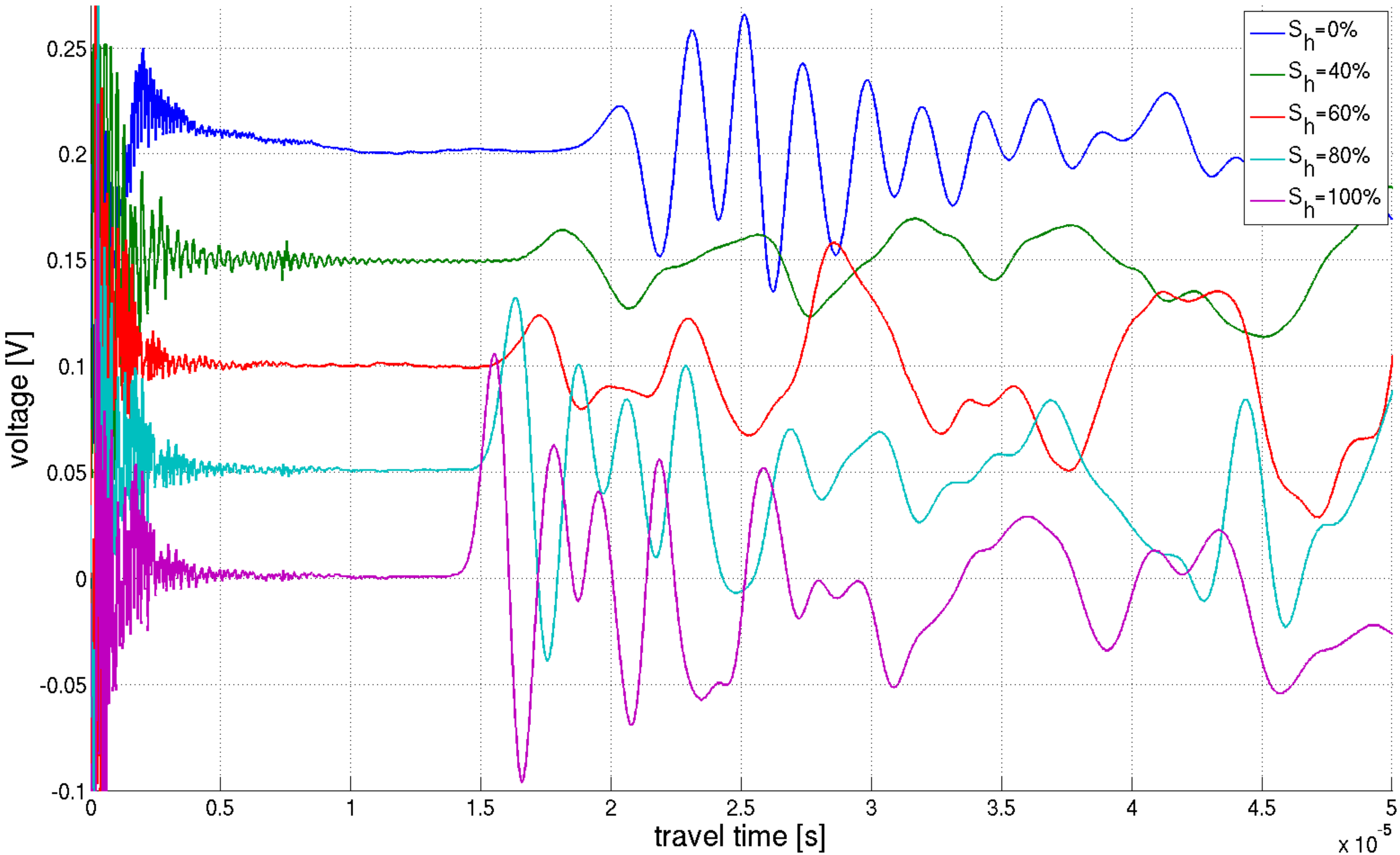
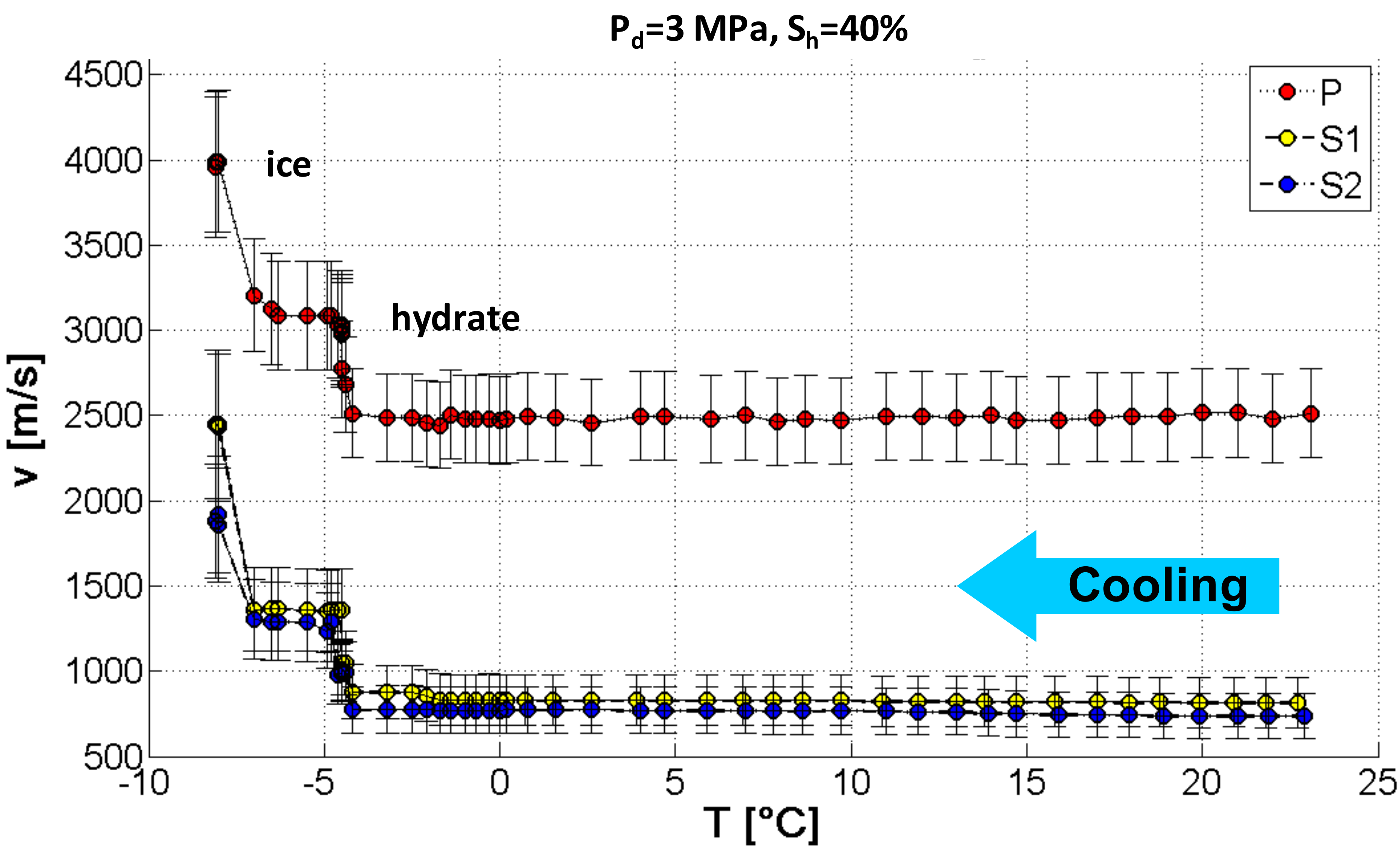


Tomograms for a glass bead sample sample with S_{GH} = 80%

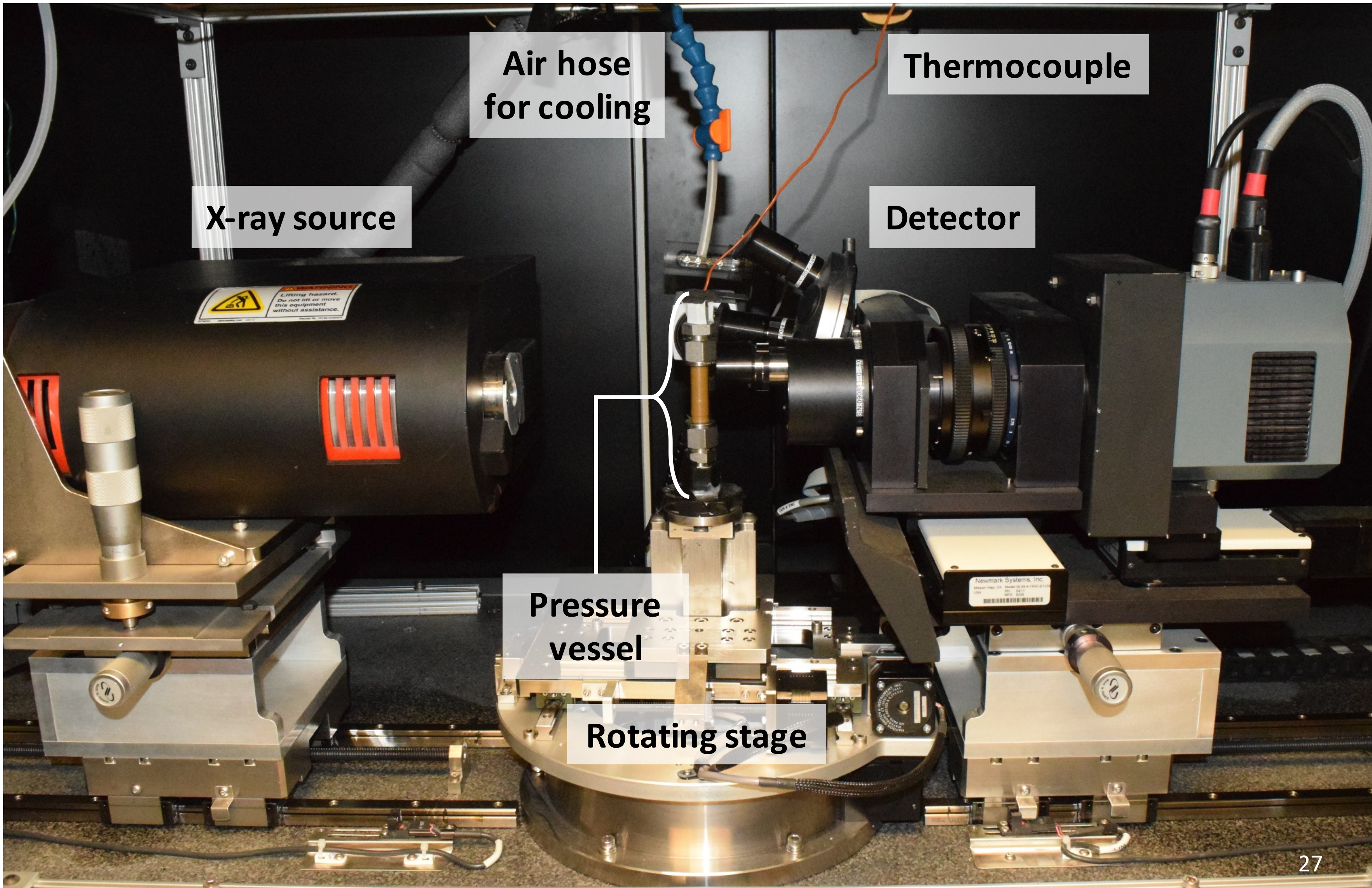


S_h=0%
S_h=40%
S_h=60%
S_h=80%
S_h=100%
voltage [V]
0.25
0.2
0.15
0.1
0.05
0
-0.05
-0.1
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
travel time [s]
x 10^-5

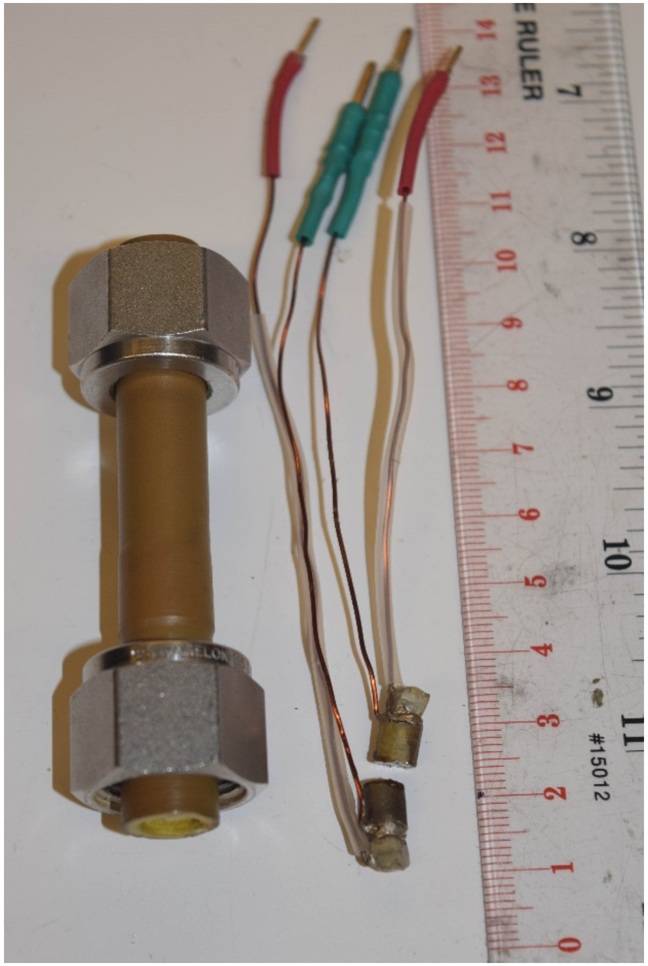
Ultrasonic Velocities

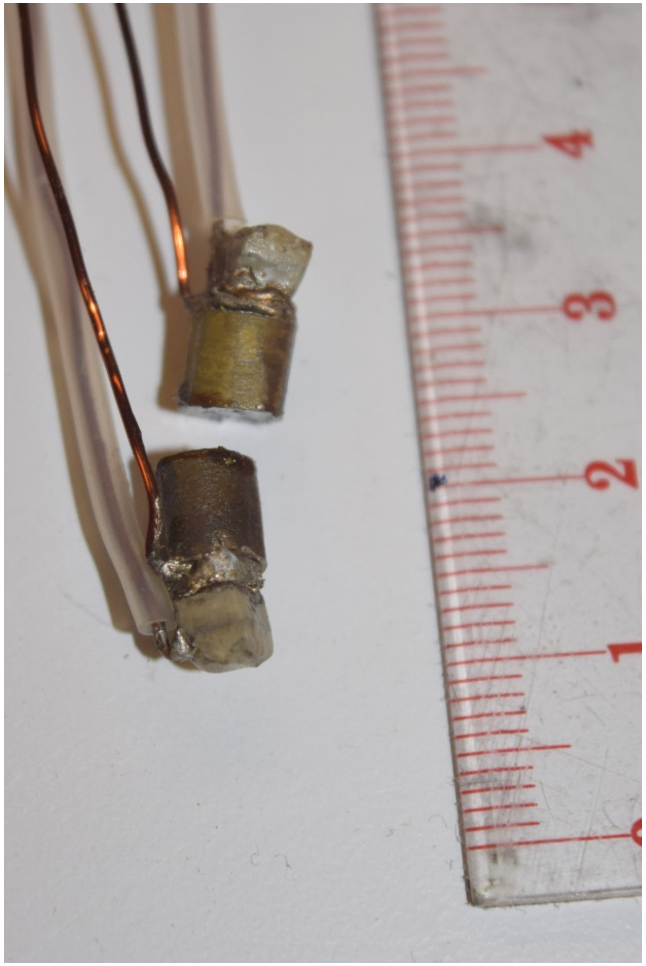


Micro CT Experimental Setup



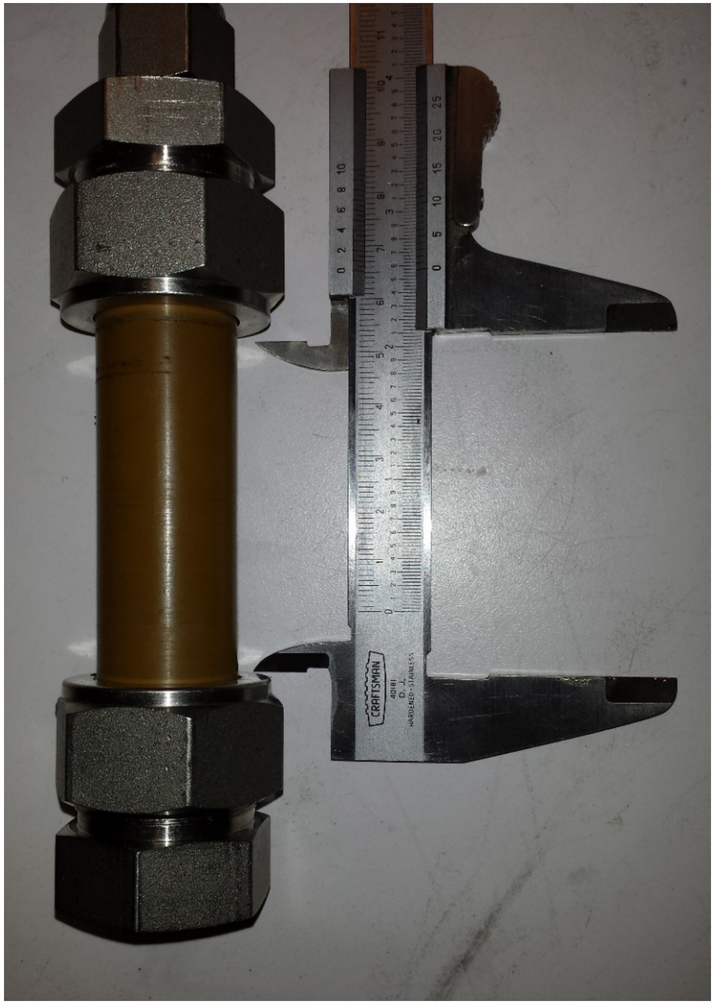
Ultrasonic Transducers

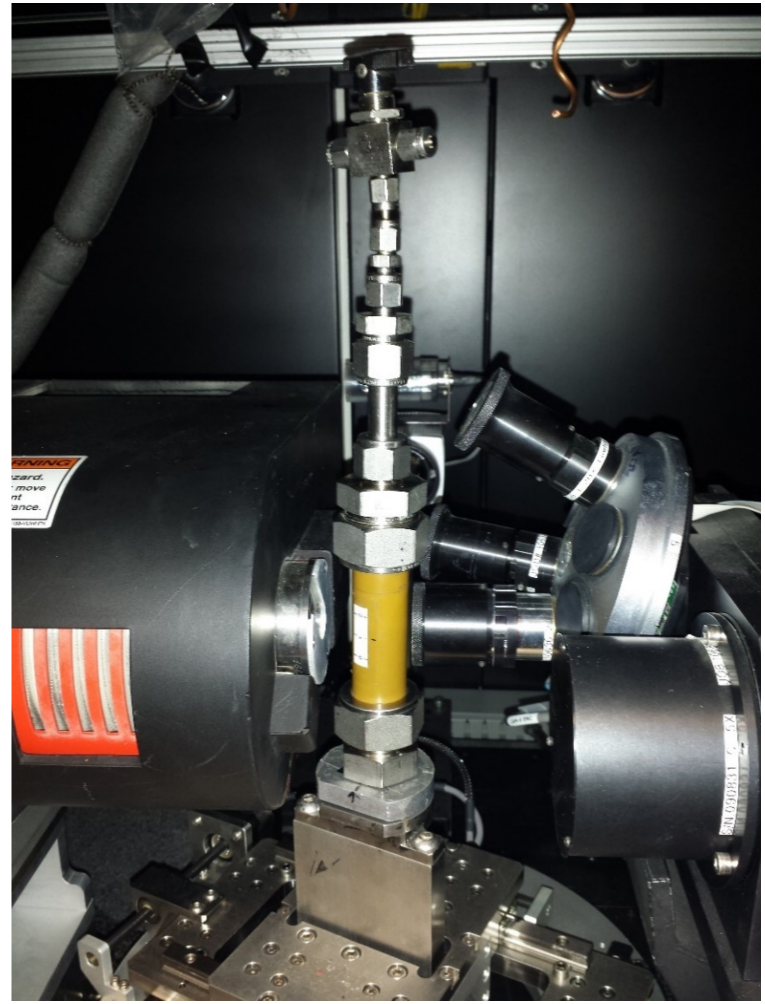




Ultrasonic transducers: P-wave only, 3 mm diameter
For use in Torlon pressure vessels

MXCT Imaging Under Pressure

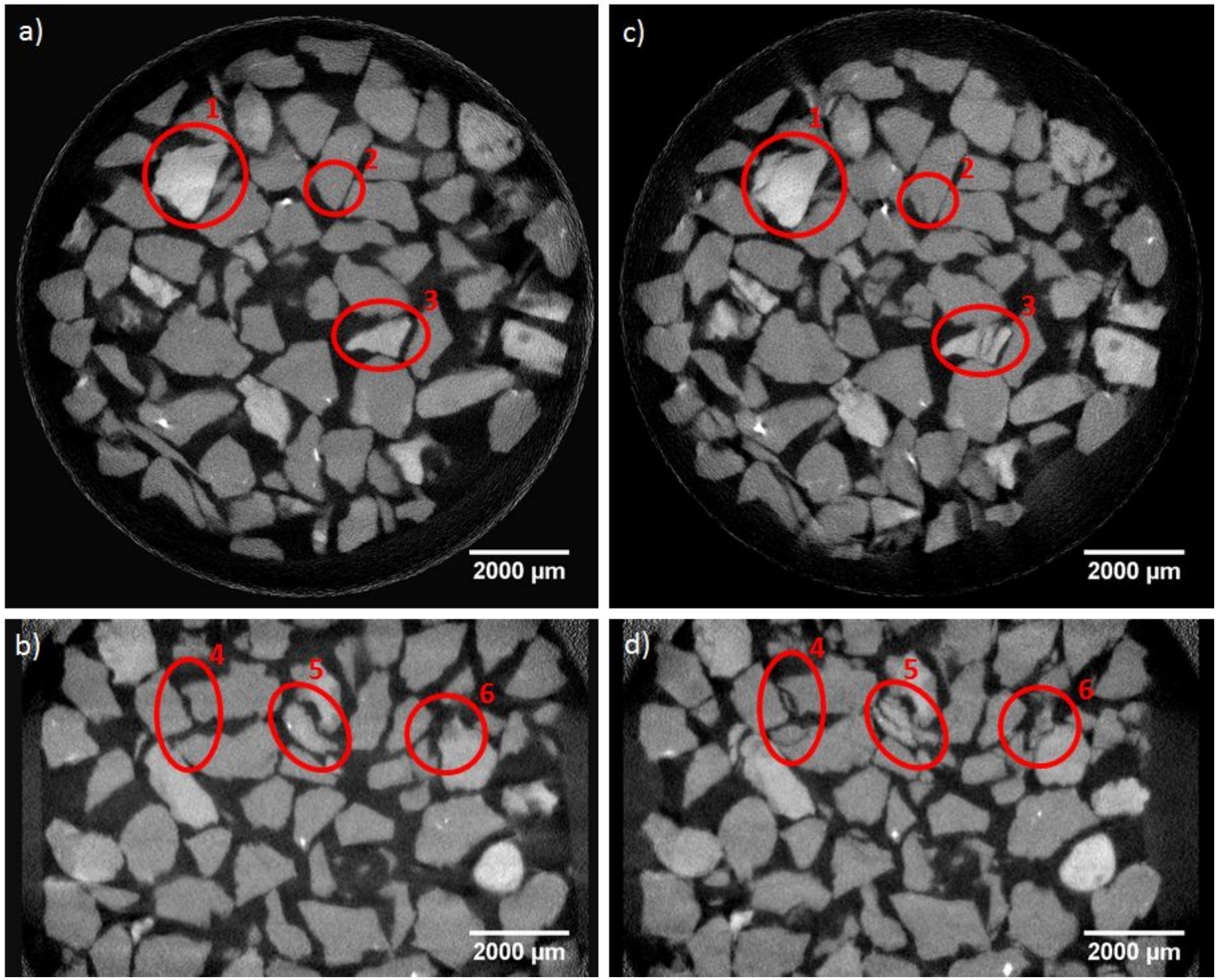




Pressure up to 5000 psi – 34.5 MPa
Inner diameter: 14 mm, outer diameter: 25.4 mm (1 inch)
Plans to include pore pressure and confining pressure

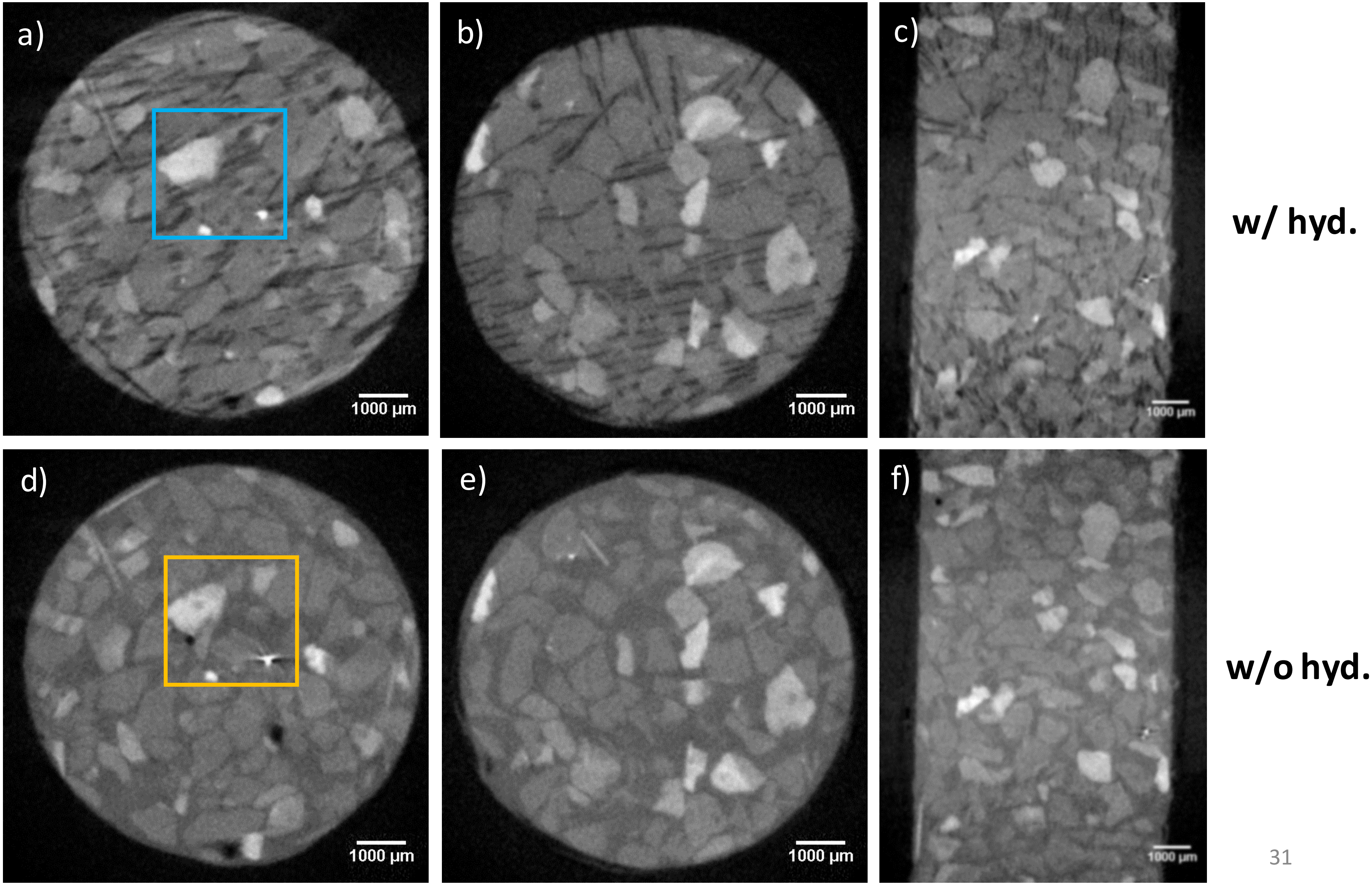
MXCT Imaging Under Pressure

atmospheric pressure | **1500 psi**

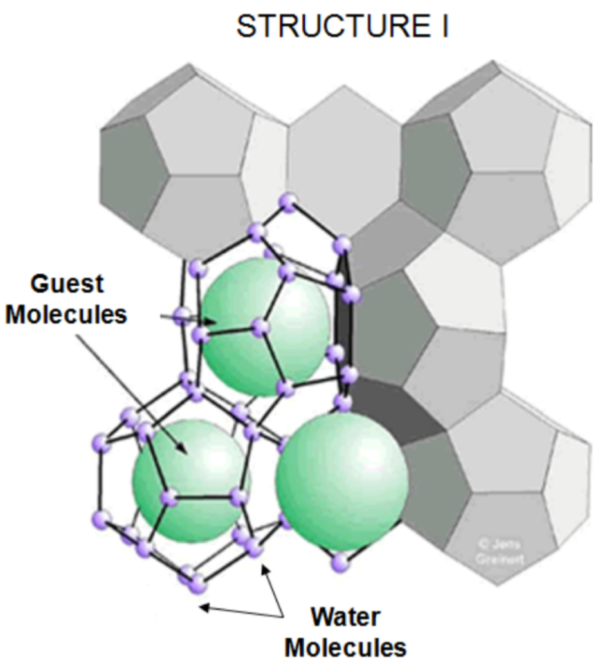


Observed grain damage and porosity reduction

Quartz With S_h=40%



Introduction



- **Low Temperature, High Pressure**

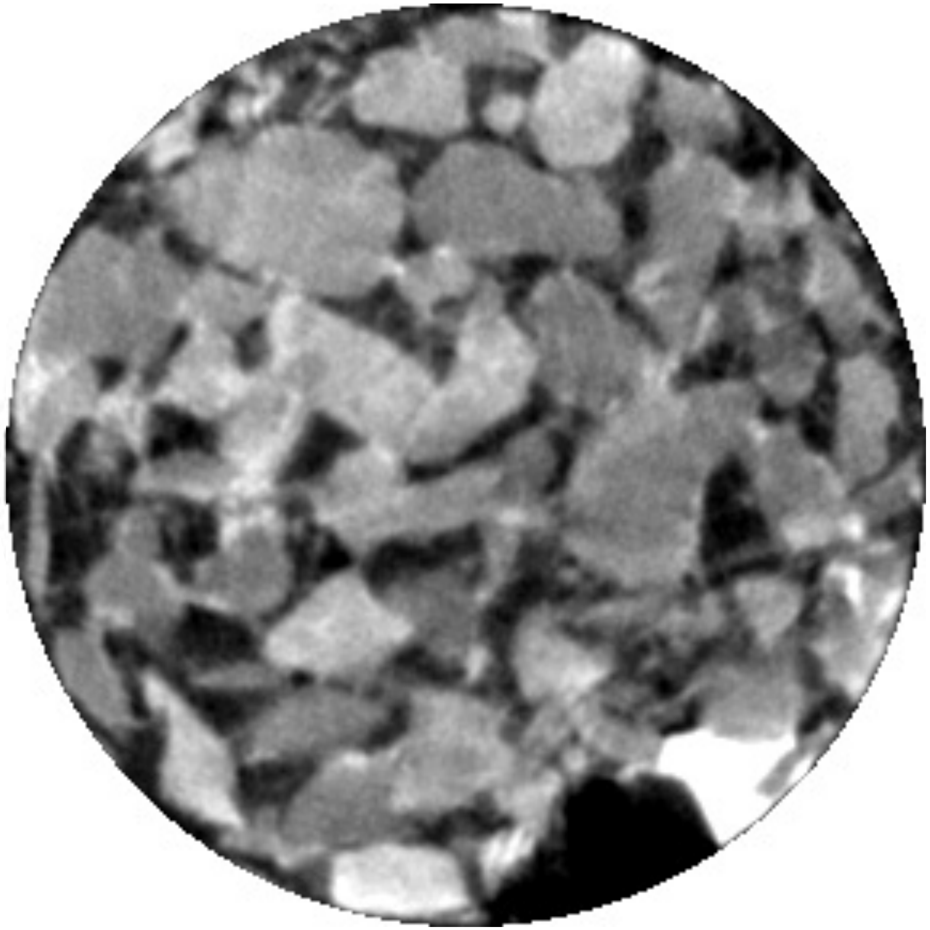
- Arctic permafrost
- Marine sediments (> 500m deep)

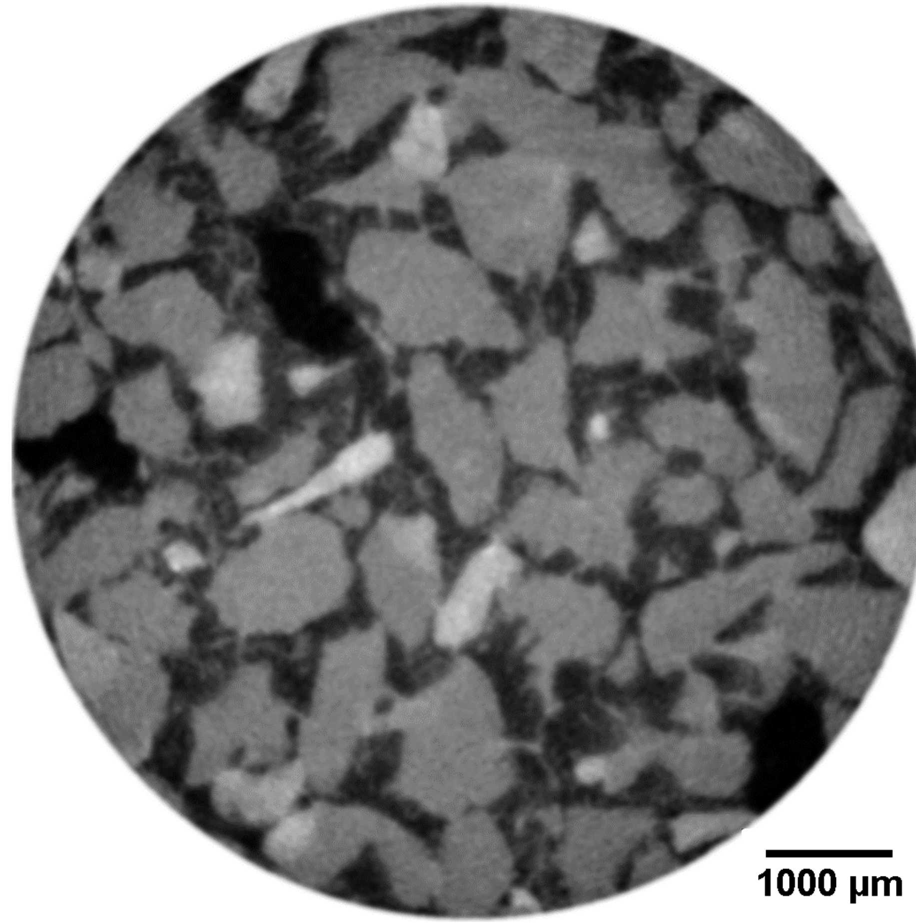
- **Availability of methane and water**

- **Formation: gas dissolved in water or free gas phase**

- **For laboratory experiments: tetrahydrofuran hydrate**

Status 1st Comps vs. 2nd Comps

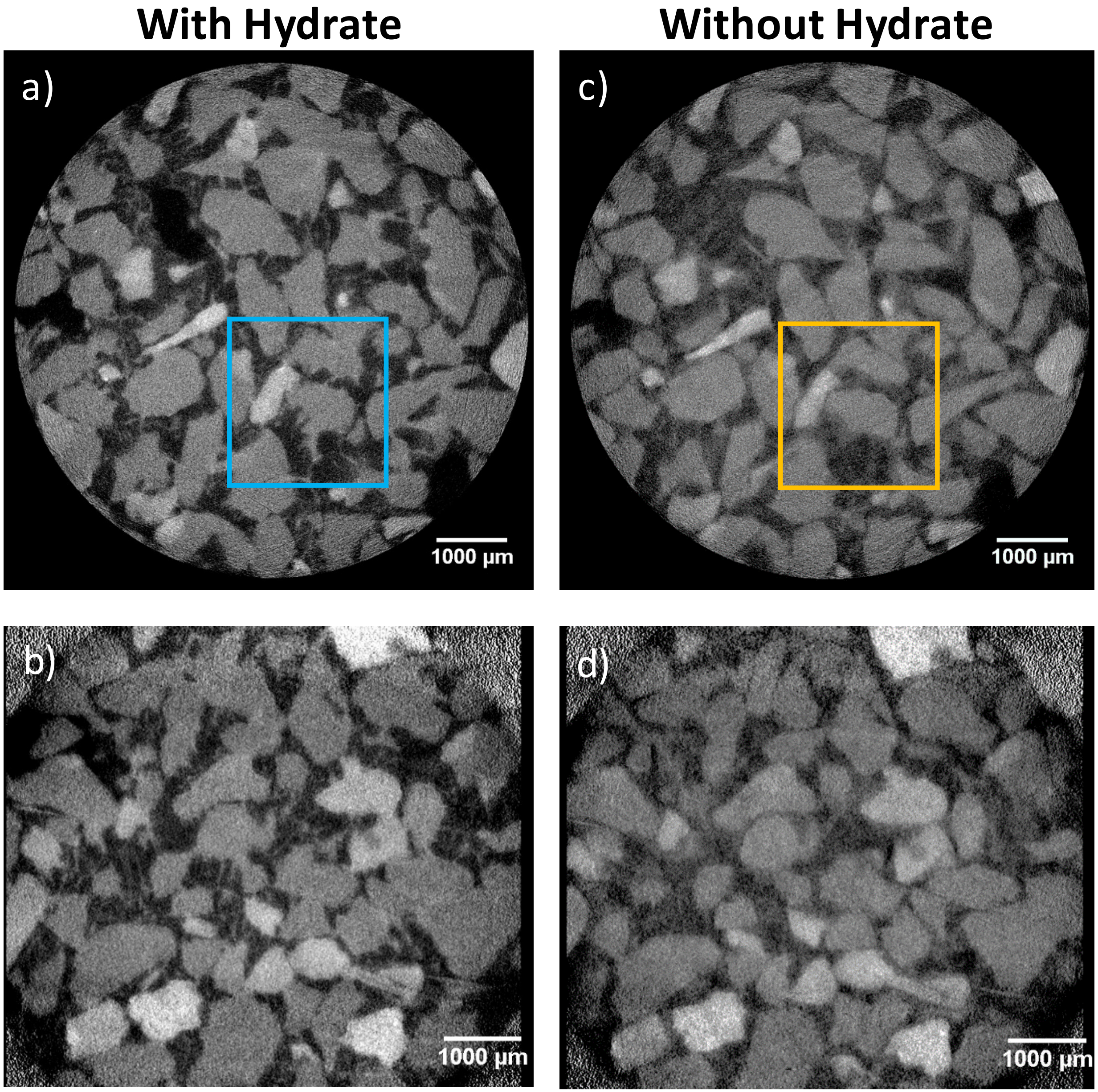


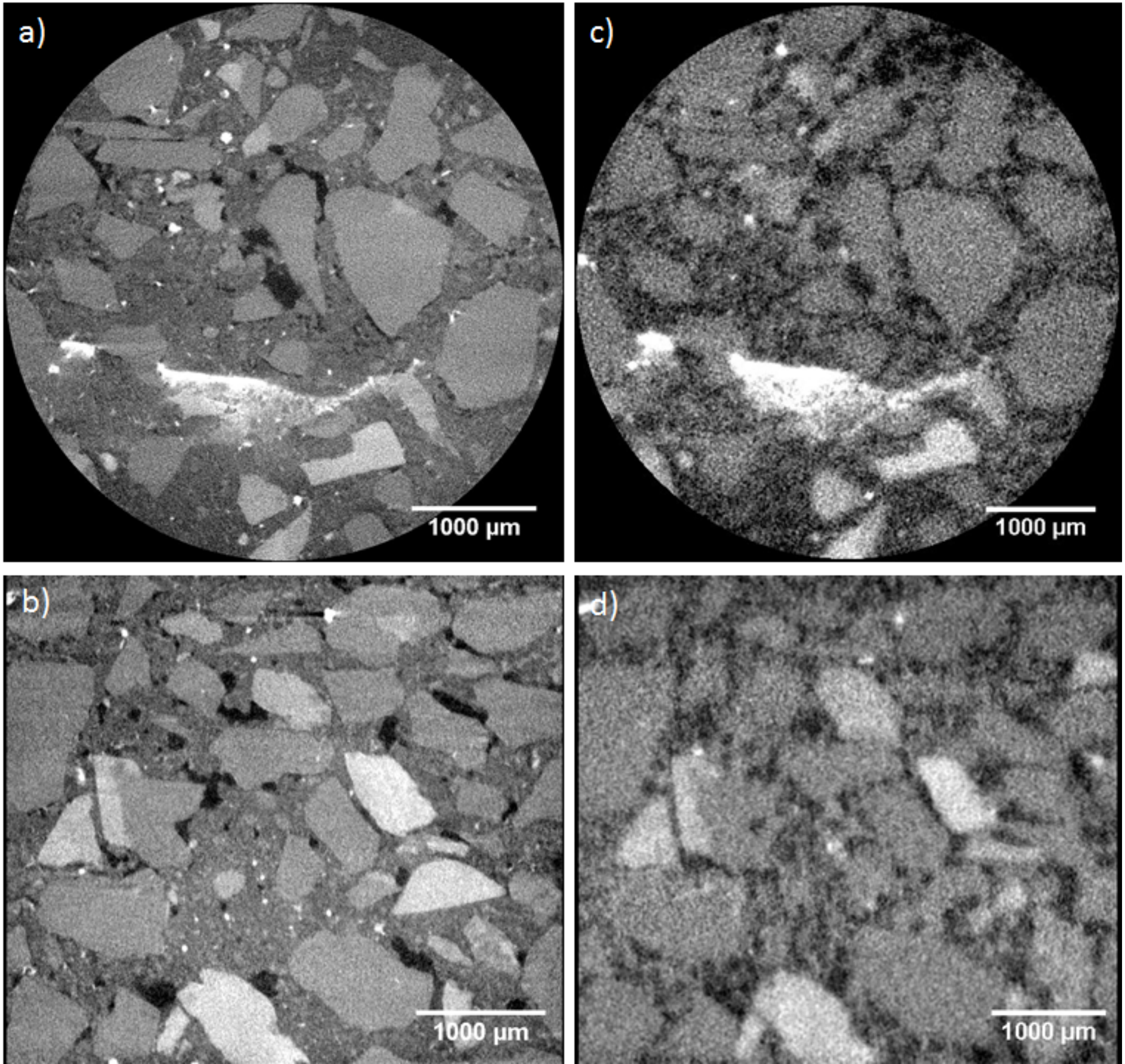


Resolution: ~70 µm
Cooling with dry ice for ~1 hour
Formation of samples outside of µCT machine
→ ice & hydrate present, not distinguishable
Glass beads as host sediment

Resolution: ~10 µm
Cooling for ~8 hours
Hydrate formation in µCT machine
Just hydrate & residual brine, no ice
Quartz sand (and clay) as host sediment

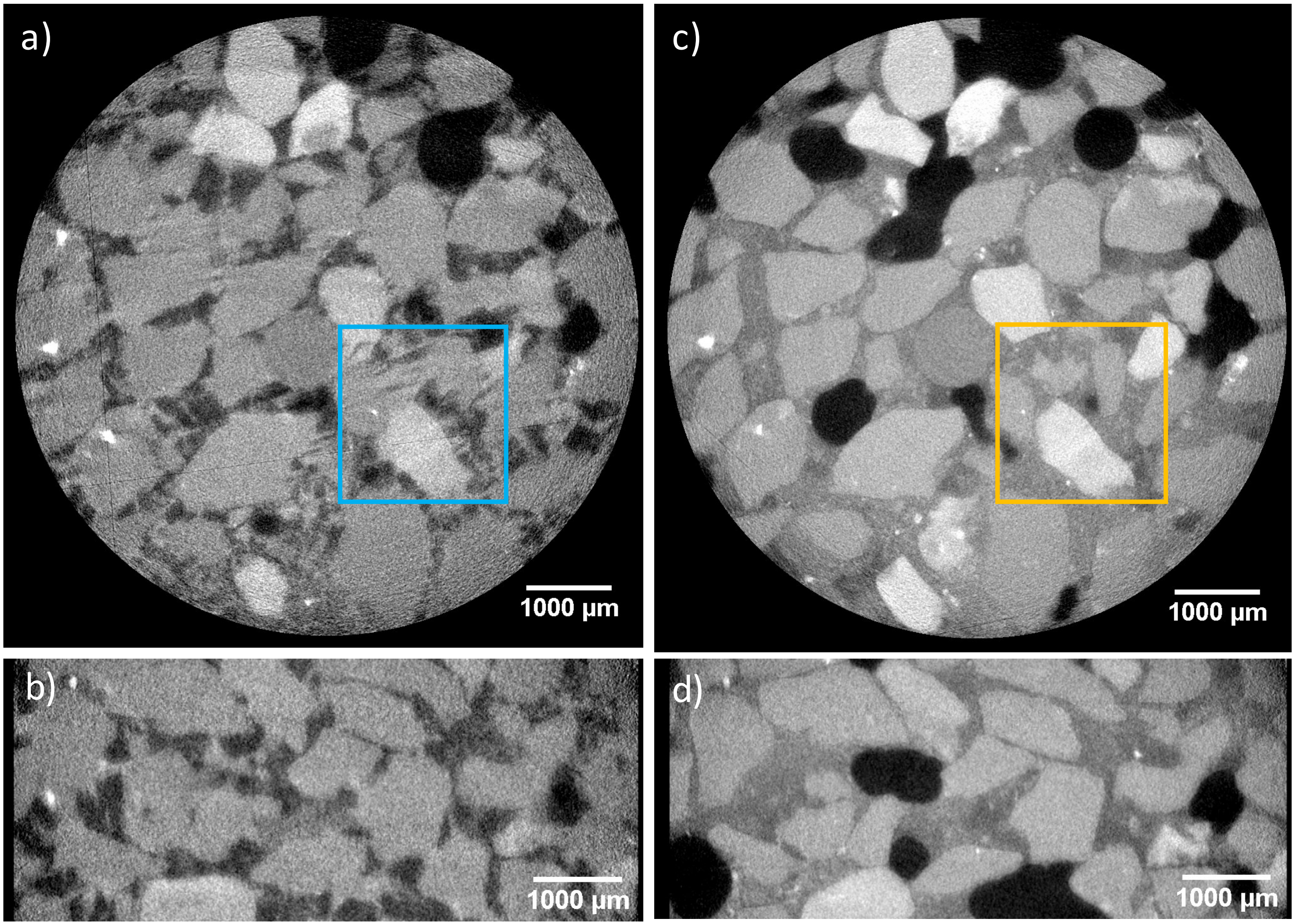
Quartz With S_h=80%



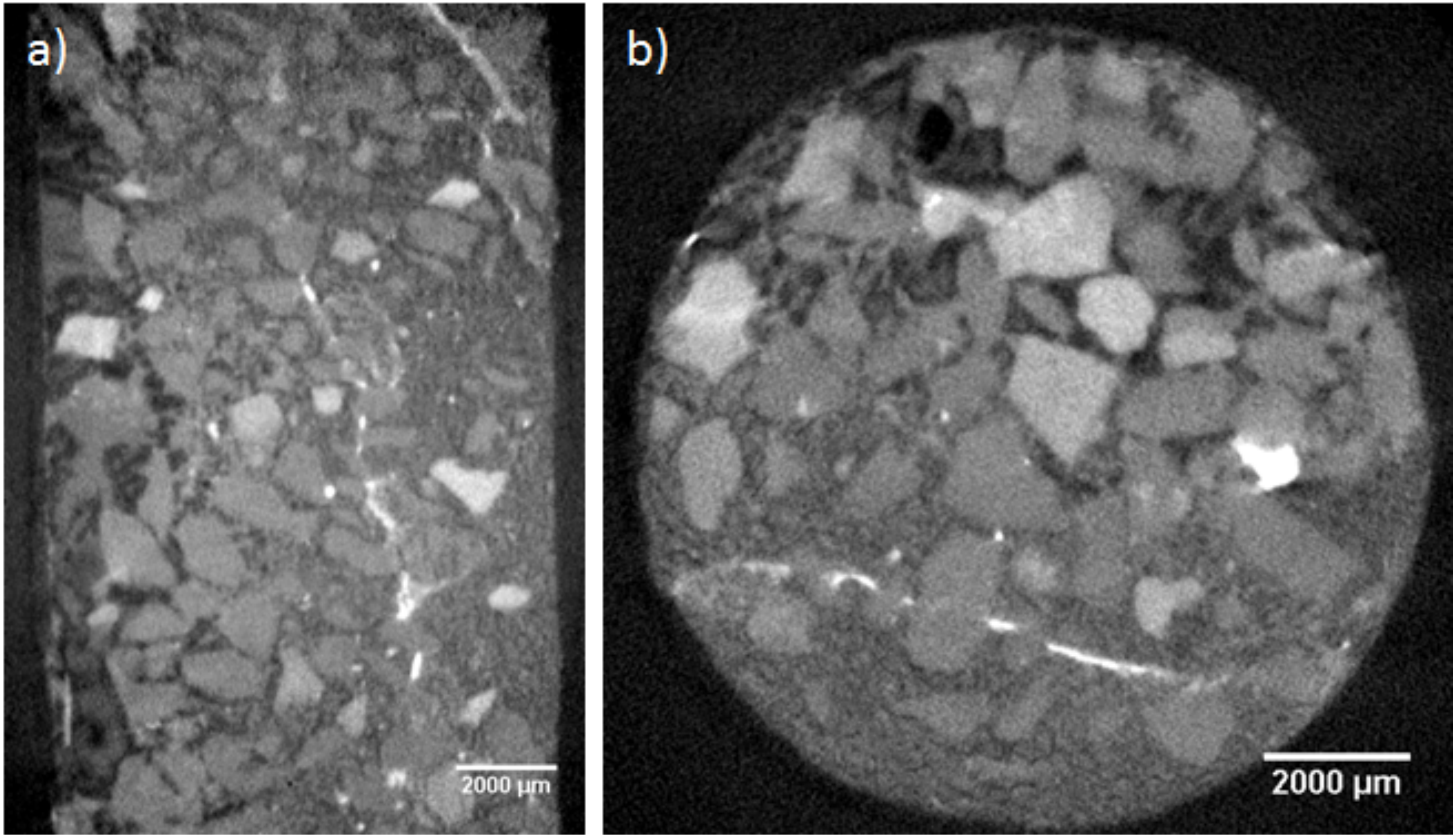

a)
1000 µm
c)
1000 µm
b)
1000 µm
d)
1000 µm

Quartz and Clay With S_h=80%

With Hydrate **Without Hydrate**



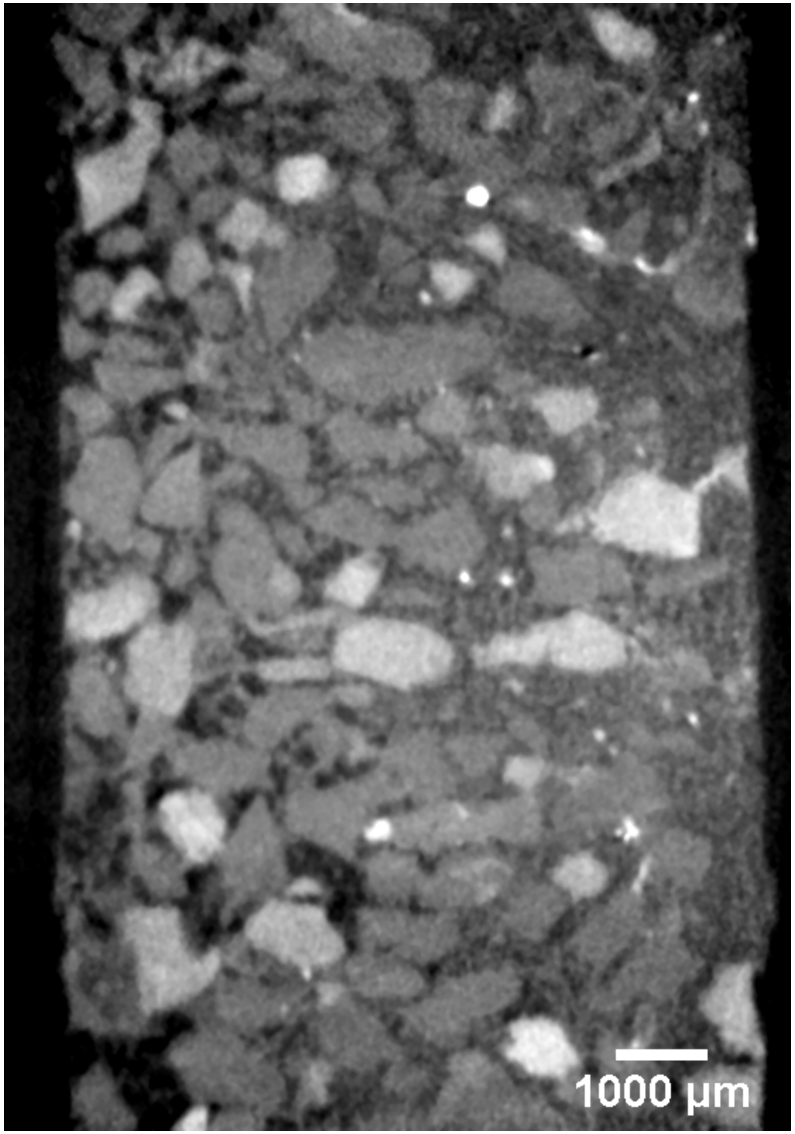
Quartz and Clay With S_h=80%



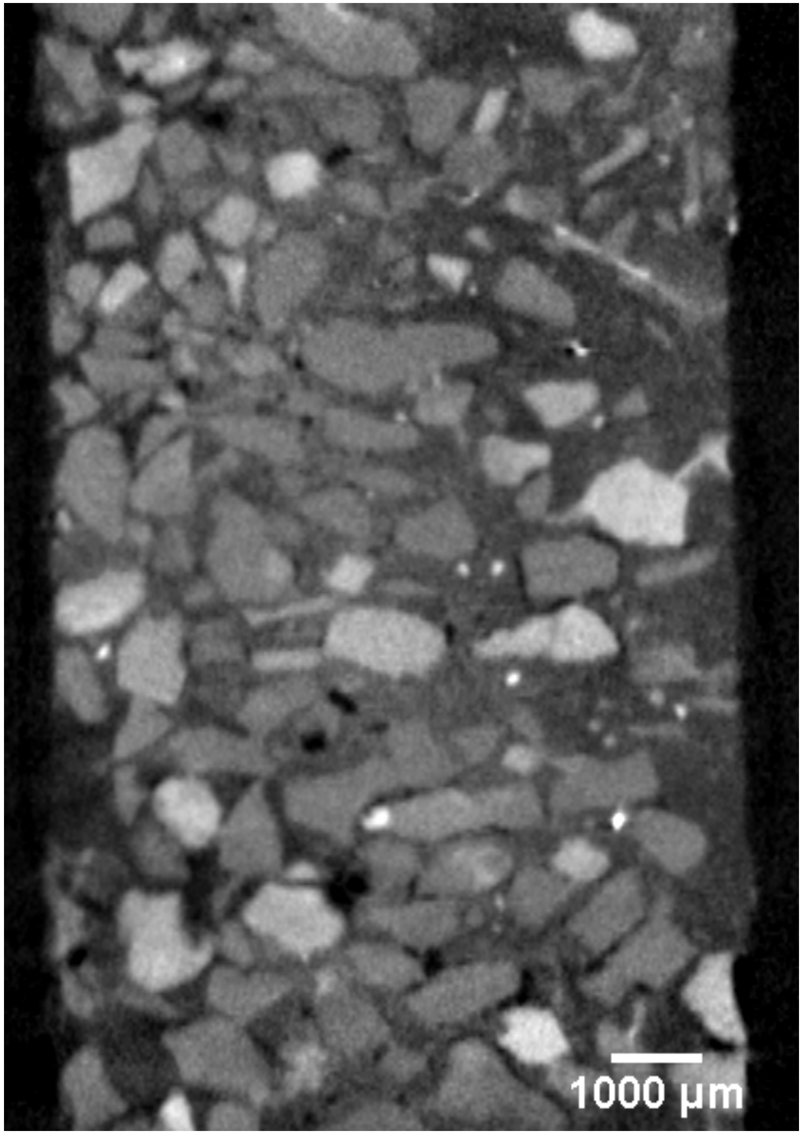
Heterogeneity in hydrate and clay distribution
Clay moved by hydrate

Quartz and Clay With S_h=80%

With Hydrate



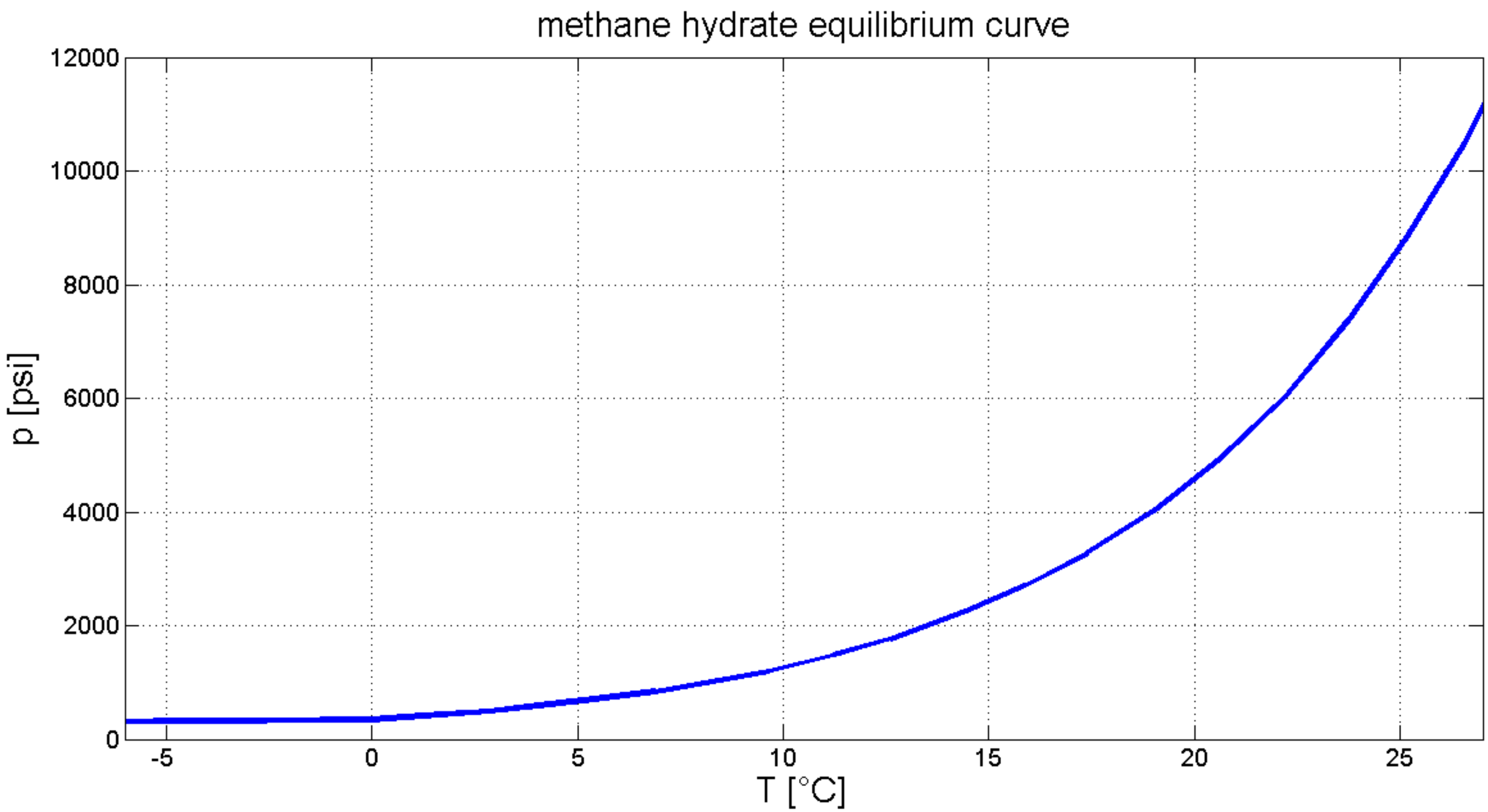
Without Hydrate



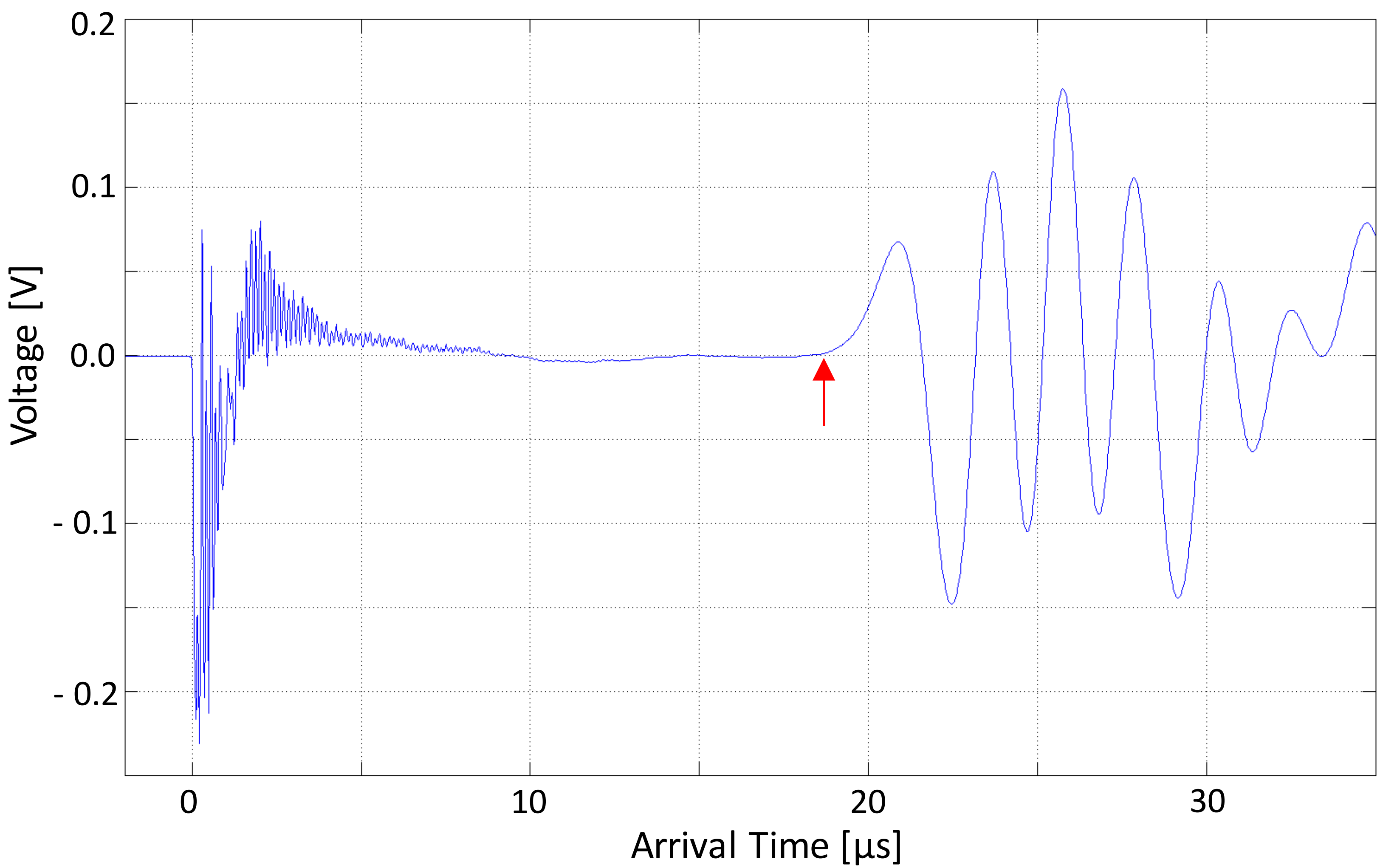
Research Scope

- Properties of pure gas hydrate well understood
- Interaction of gas hydrate and sediment less so
- Elastic properties of gas hydrate bearing sediments
  e.g. Waite, Priest, Spangenberg
- Imaging of gas-hydrate bearing sediments
  e.g. Kerkar, Sell
- Combination of imaging and elastic properties:
  e.g. Kneafsey & Nakagawa
- Pore-scale imaging & elastic properties → MY NICHE

Methane hydrate equilibrium curve



Test Waveform on Bentheim Sandstone



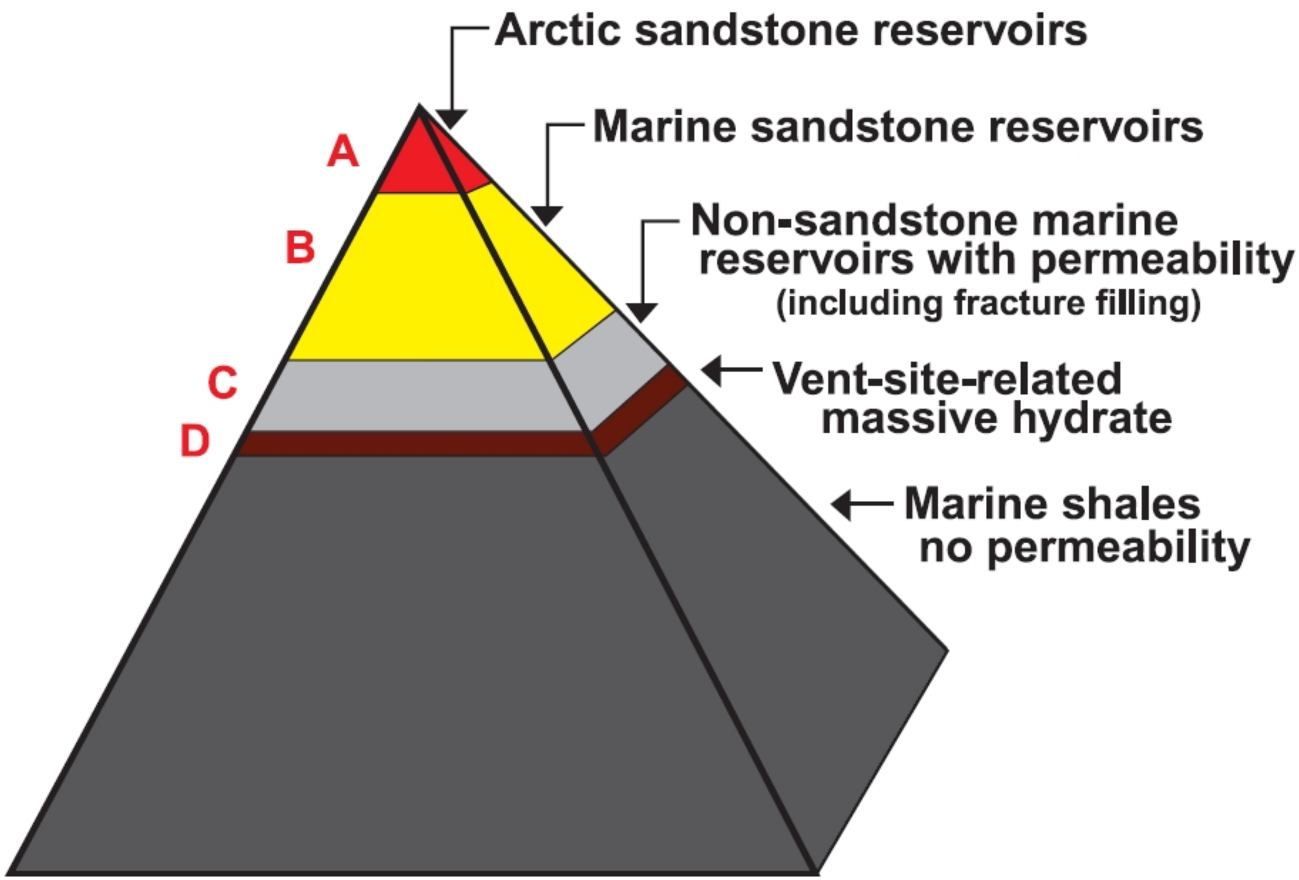
Calculated P-wave velocity: 1687 m/s

Sample Components

Component	Density [g/cm^3]
water	1.00
$BaCl_2$	$3.84^{(a)}$
$BaCl_2$ brine (12.3 wt%)	1.1
THF hydrate	$0.97^{(b)}$
THF-water-$BaCl_2$ mixture	1.00

Types of Gas Hydrate Deposits

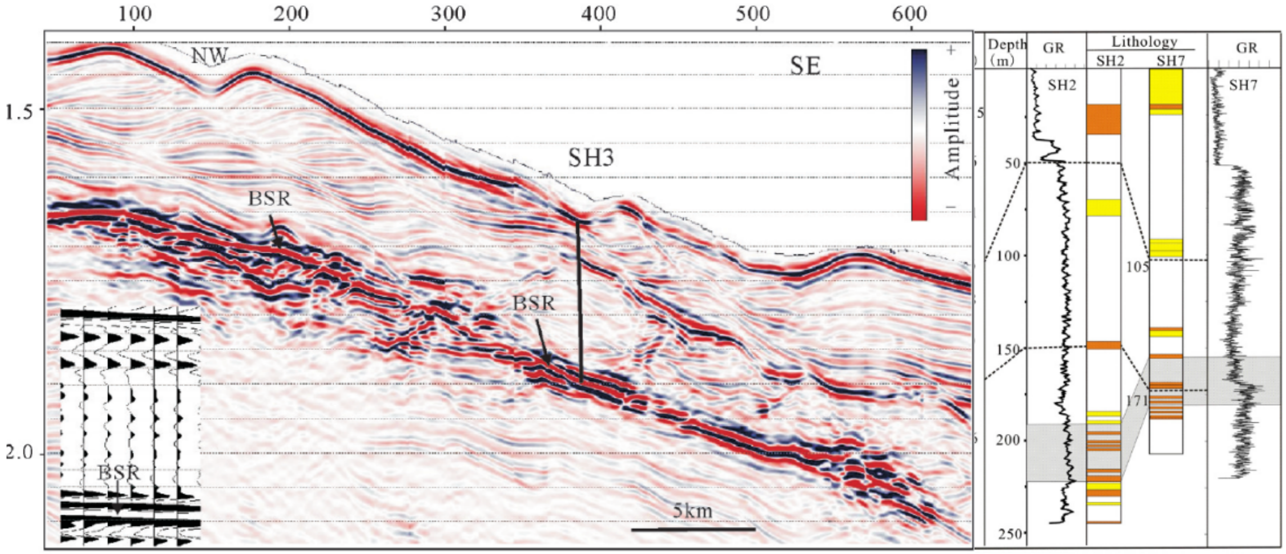
Estimated amount of methane stored in hydrates :
10^{15} to 10^{18} m^3 (STP) **(methane in conventional reservoirs: $4*10^{13}$ m^3)**



Collett and Boswell, 2006

Measured Samples

S_h	Host Sediment	μCT	Ultrasonic
40%	glass beads	2	1
40%	quartz sand	2	0
60%	glass beads	0	2
80%	glass beads	2	1
80%	quartz sand	2	0
80%	quartz sand with bentonite	1	0
100%	glass beads	0	1

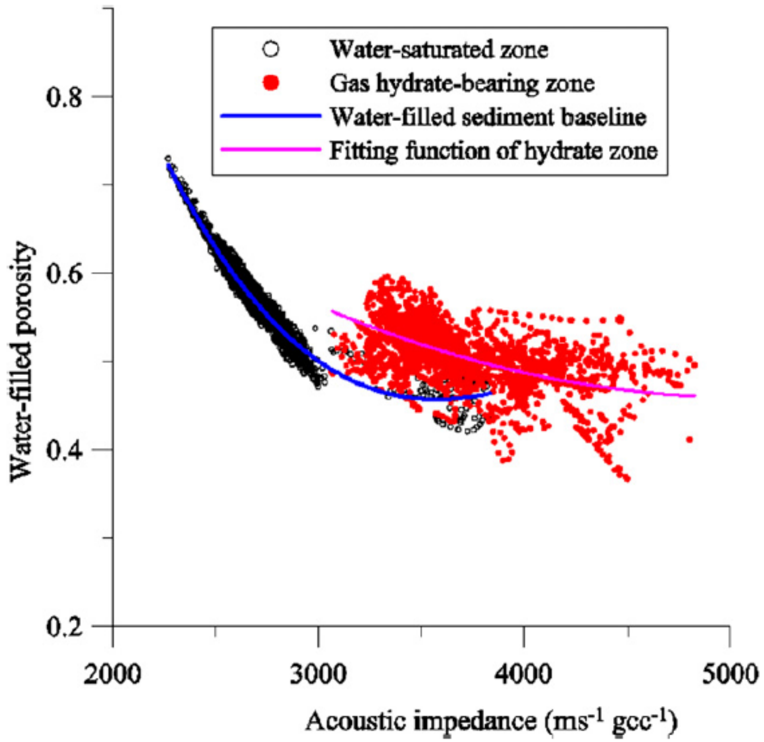


Wang et al., 2011

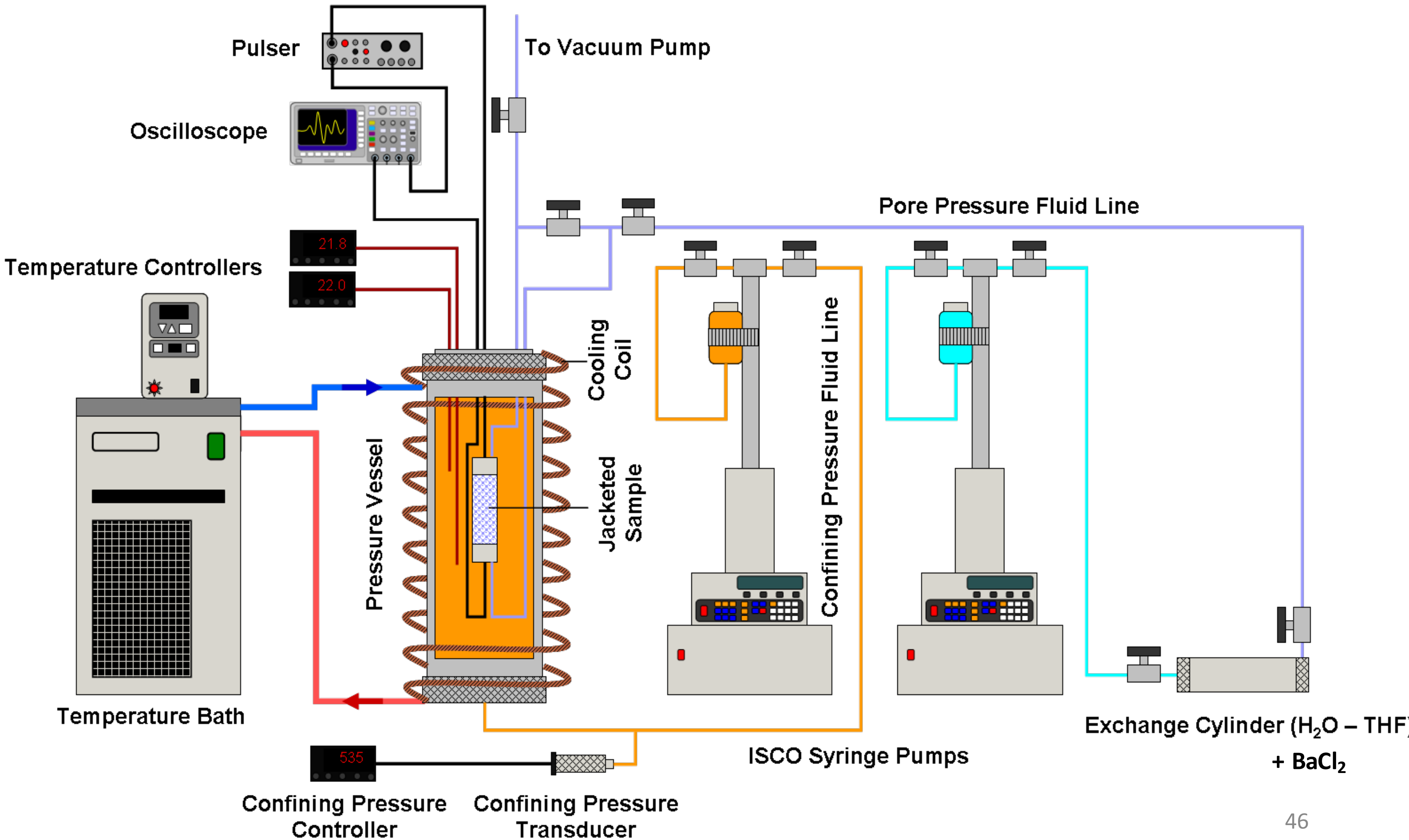
- **Use of seismic and well logs**
- **Hydrate saturation from Archie's equation**
- **Connected to acoustic impedance by empirical relationship**
- **Physical model preferred over empirical**

→ **Use sonic logs to quantify hydrate saturation**

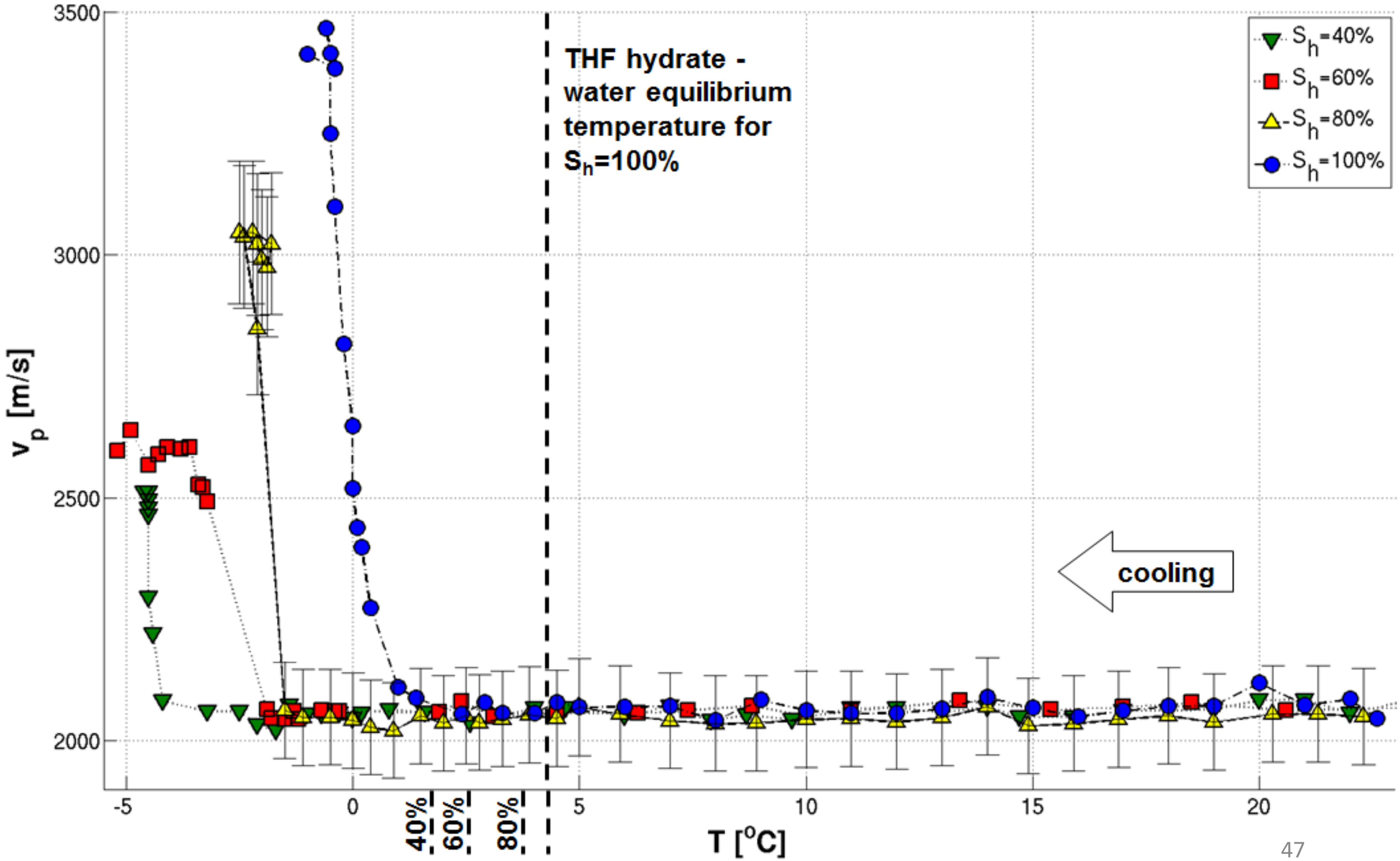
→ **connect to seismic (acoustic impedance)**



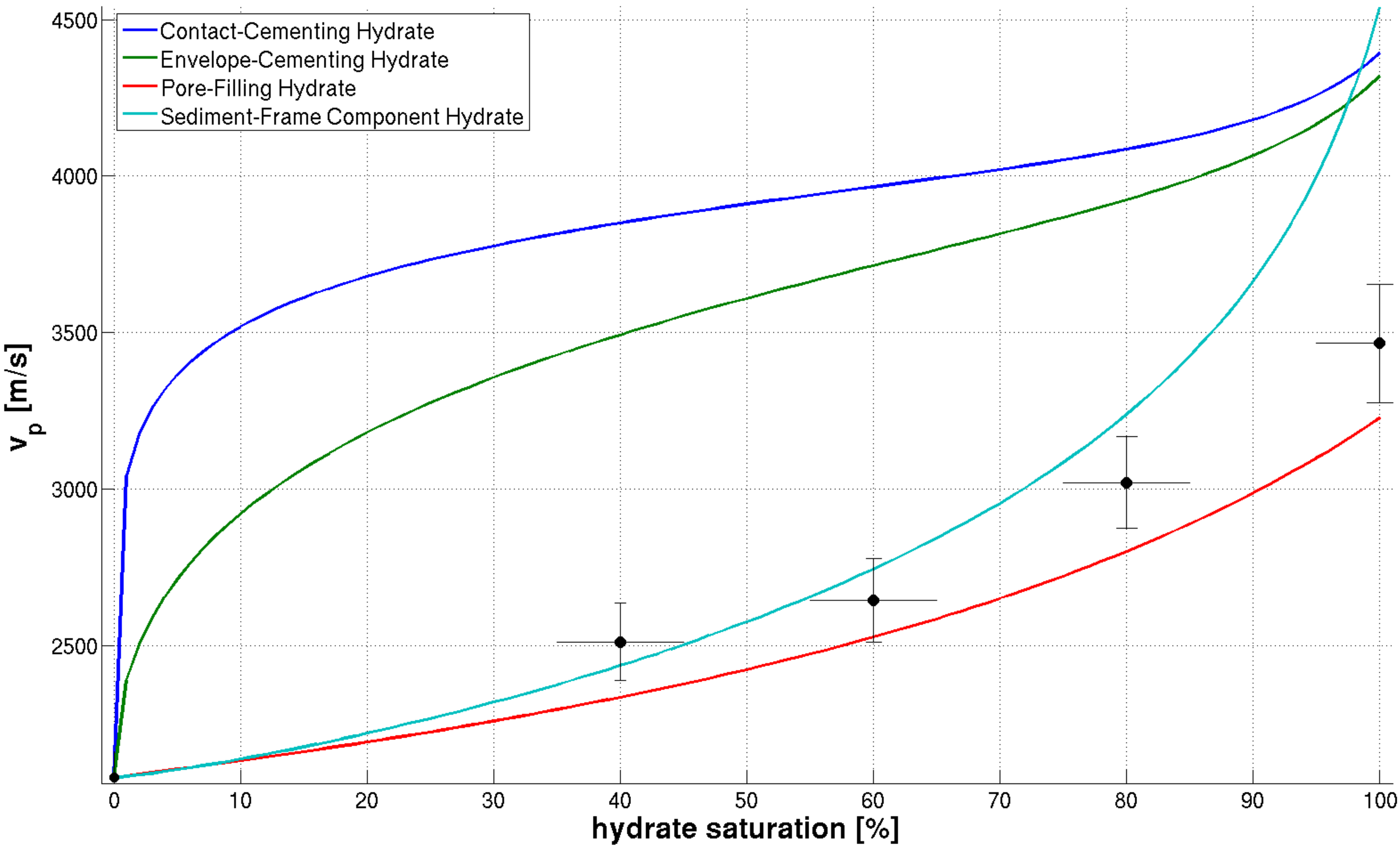
Ultrasonic Velocity Measurements

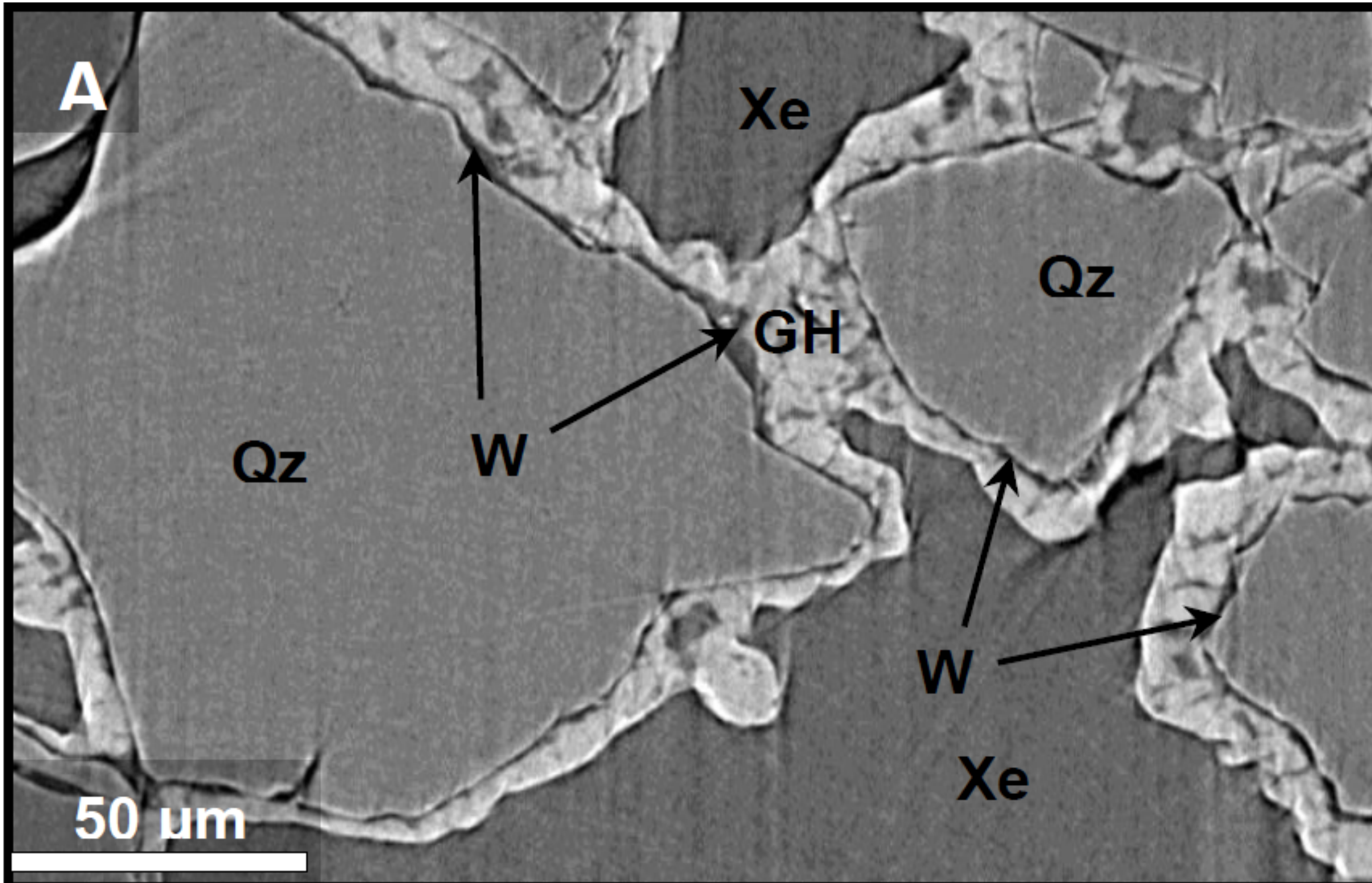


Different Hydrate Saturations



Effective Medium Models: P-Wave





Sell et al., 2015

NMR Signals

from Pohl, Prasad, Batzle, *submitted to Geophysical Prospecting*