BEHAVIOR OF SEDIMENTS CONTAINING METHANE HYDRATE, WATER, AND GAS SUBJECTED TO GRADIENTS AND CHANGING CONDITIONS

FP00008137

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LBNL Gas Hydrate Lab Objectives

- Measure physical, chemical, mechanical, and hydrologic property changes in sediments containing methane hydrate, water, and gas subjected to varying stimuli and conditions.
  - effects of of other gases (CO_2, N_2, mixtures)
  - effects of sediment layering
  - effects of stress
  - effects of relevant gradients (thermal, chemical (salinity or gas composition), and capillary pressure) on hydrate behavior.
- All tests are non-standard and new techniques must be developed.

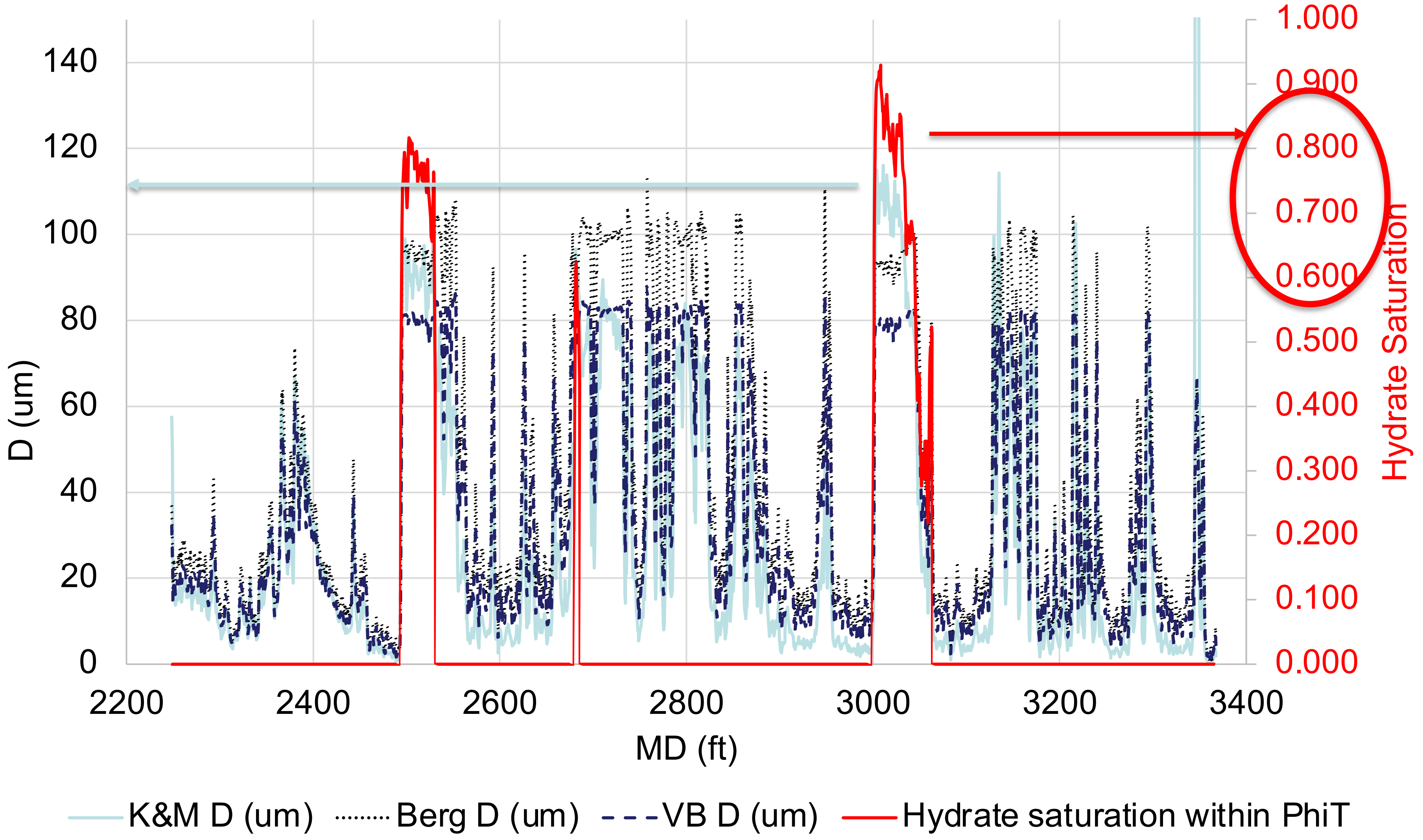
Issues this FY

- 2 Public Safety Power Shutoffs
  - Complete lab shutdown and restarts
- Working with TAMU on hydrate relative permeability
- COVID 19
  - SIP, limited access, slow start
- Equipment issue

Project Objectives

- Laboratory benchmark geomechanical tests for code validation
  - *Design task with feedback from geomechanical modelers*
  - *Test design and construction in existing or off-the-shelf pressure equipment*
  - *Perform a series of tests (cementing hydrate)*
  - *Devise transfer method/sample composition for pore-filling hydrate*
  - *Perform tests on pore-filling hydrate*
- Geomechanical evaluation - compaction of hydrate-bearing and non-hydrate-bearing Alaska Field Test relevant sediments under relevant conditions, layered samples

Alaska Media Summary



International Gas Hydrate Code Comparison 2

Title: An International Code Comparison Study on Coupled Thermal, Hydrologic and Geomechanical Processes of Natural Gas Hydrate-Bearing Sediments

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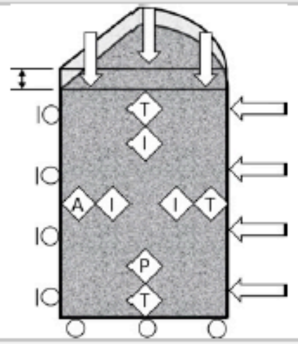
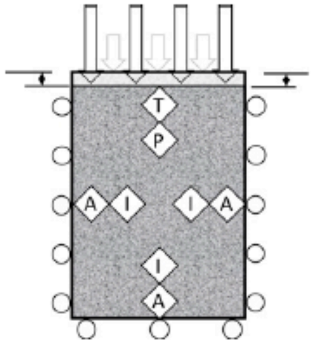
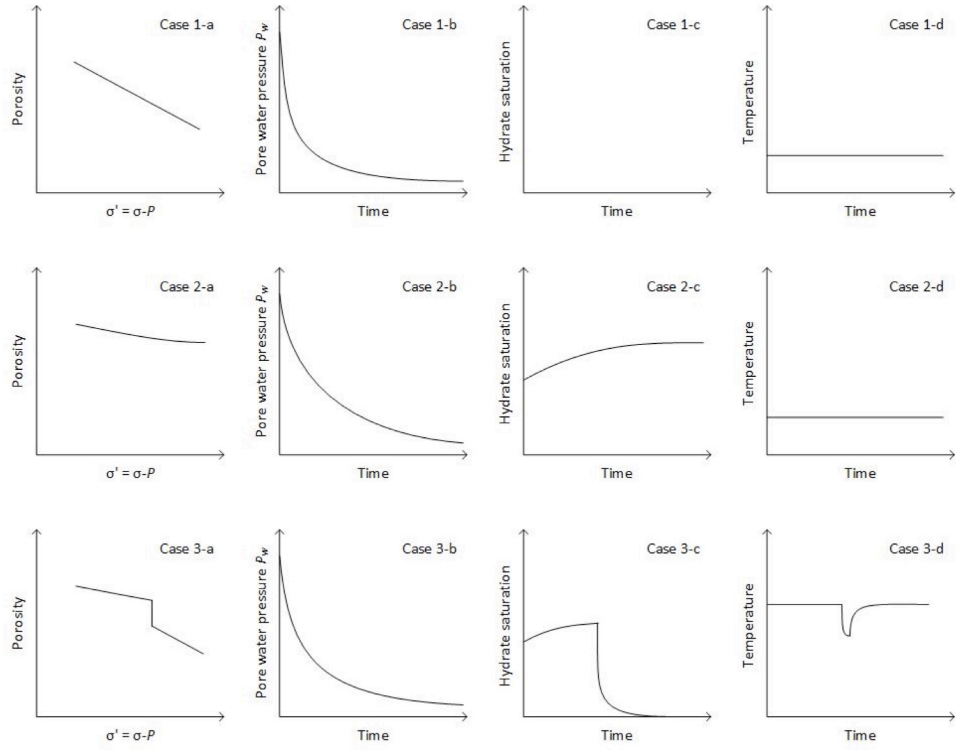
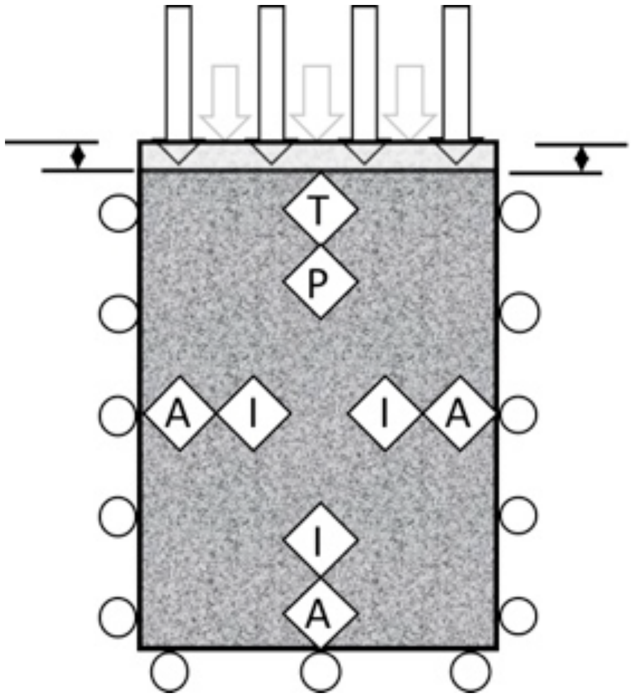
Two Benchmark Problems From the IGHCC2 Study

BP1 (Isotropic Consolidation with Hydrate Dissociation)	
	Summary: Vertical consolidation of a single, cylindrical grid cell. Homogeneous system.
	Case 1 - No hydrate
	Case 2 - Hydrate without dissociation
	Case 3 - Hydrate with dissociation
BP2 (Extended Terzaghi Problem)	
	Summary: Vertical consolidation and relaxation of a homogeneous system of sediment, water, gas, and hydrate
	Case 1 - No hydrate kinetics
	Case 2 - With hydrate kinetics
	Case 3 - With higher hydrate contribution to sediment strength
	Case 4 - Very fast hydrate kinetics

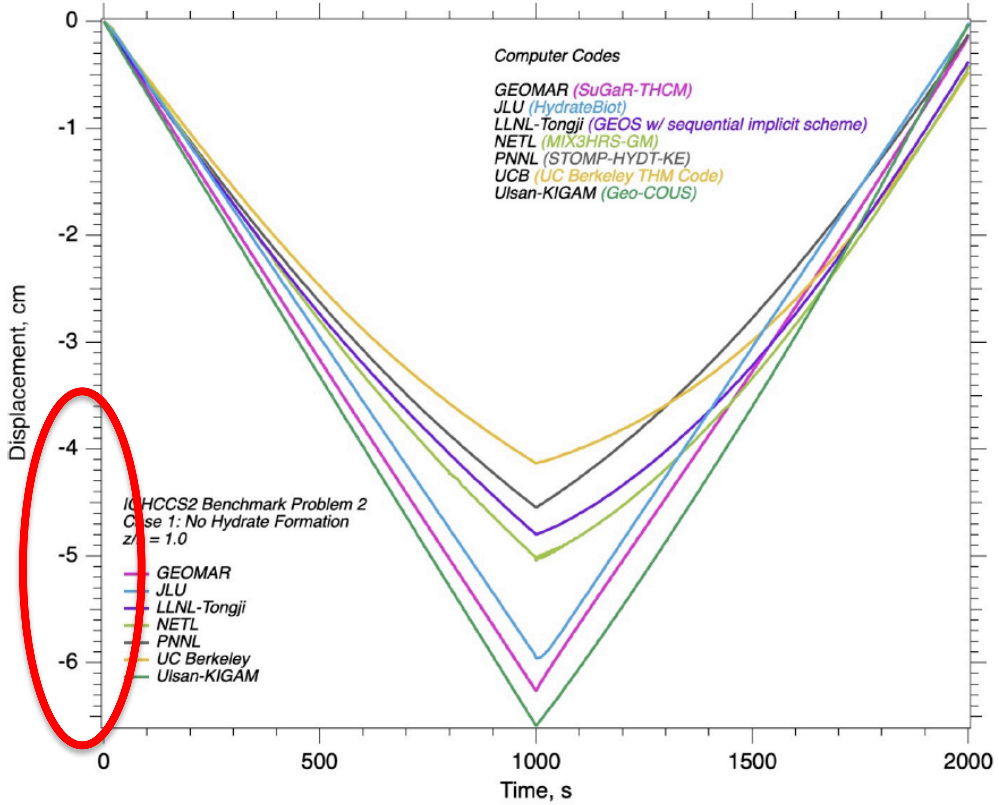


Extended Terzaghi Problem

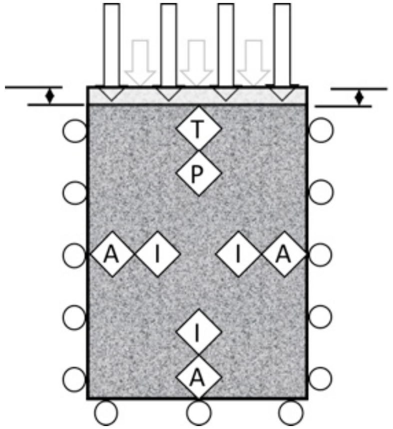
- How does the consolidation occur?
- Can we track it spatially?

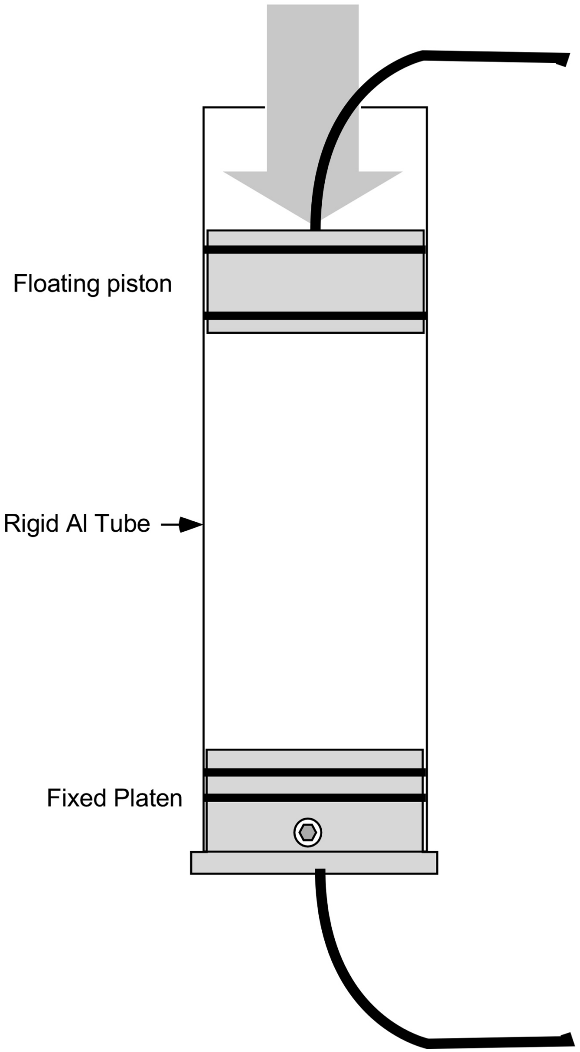


Remember this order of magnitude (4 – 6 cm / meter)

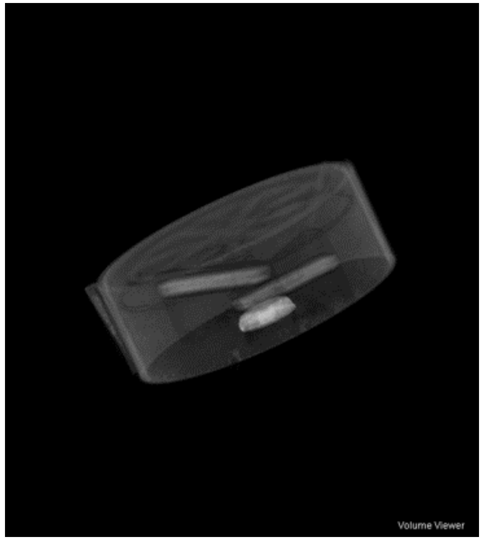


Terzaghi test apparatus design

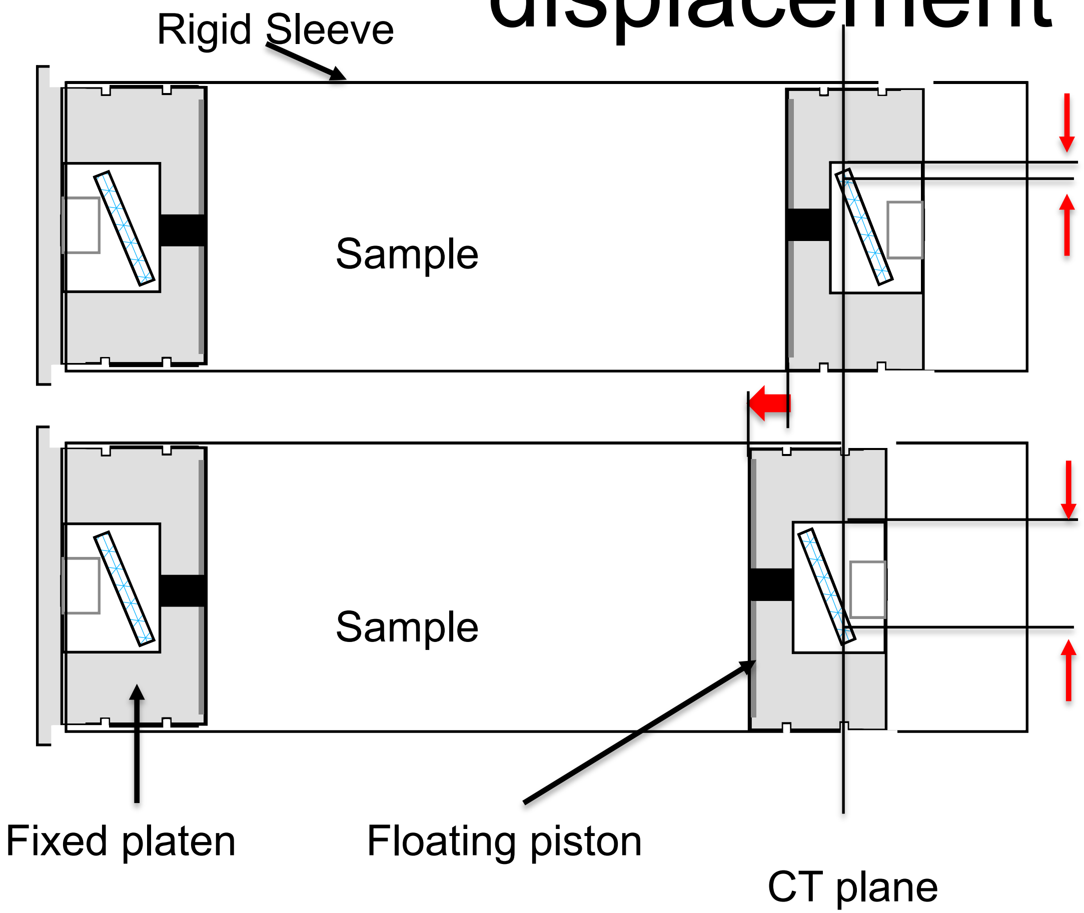




Endcaps with Al coupons for measuring endcap movement



"New" concept – Use inclined plane for subvoxel displacement measurement

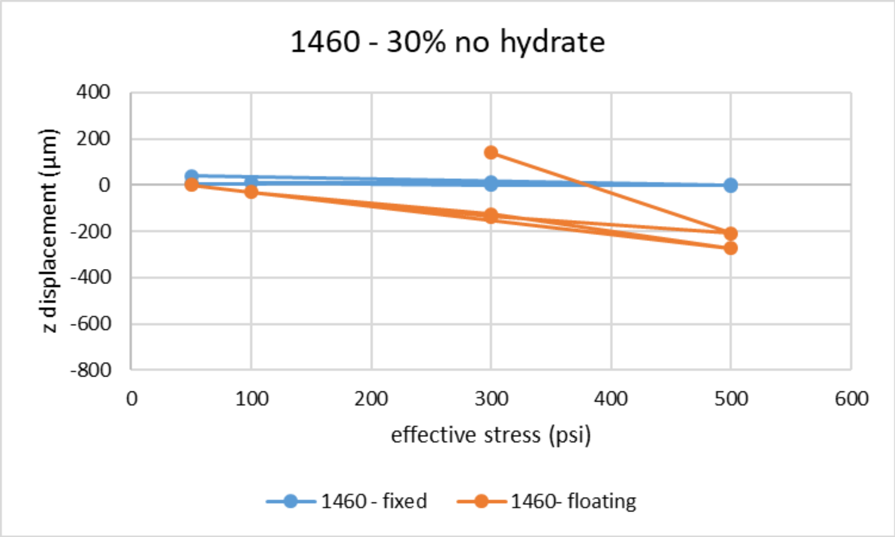


Small axial translation yields large signal on CT plane

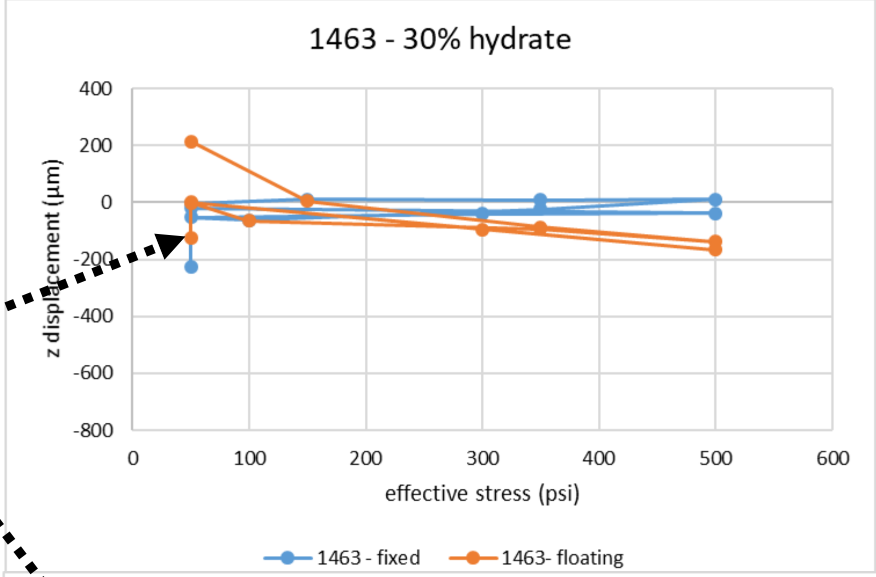
Use slanted X-ray visible coupon in platen and piston
Axial displacement is shown as lateral displacement and sensitivity is controlled by angle of coupon

Terzaghi cementing* hydrate – 30% saturation

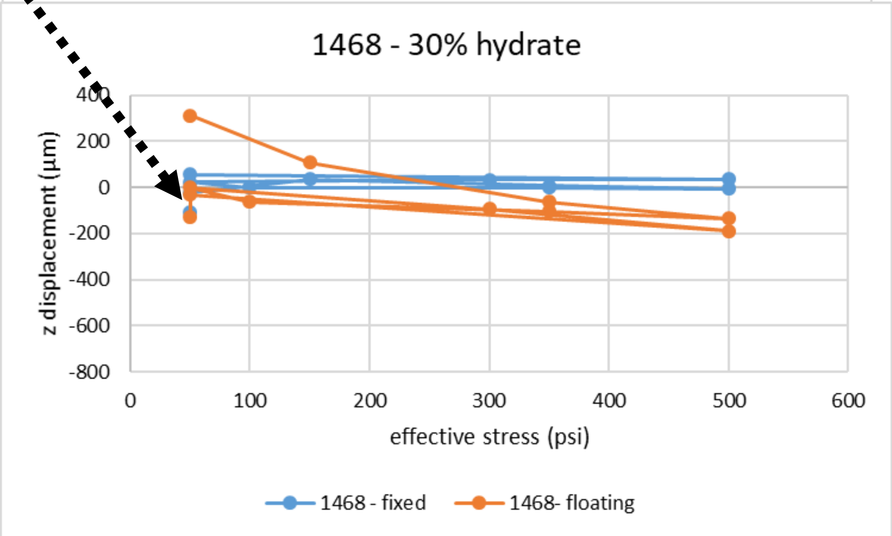
Before hydrate formation



After hydrate formation (2 replicates)



Shift during dissociation



- Sample packed with F110 sand, 30% water saturation. Pore pressure 550 psi, confining 600 psi, 20° C.
- Confining pressure was cycled 2x from effective stress of 50 to 500 psi. Observed some initial large shift of piston from initial compaction.
- Temperature was lowered to 2° C allowing hydrate to form. After hydrate formation sample was saturated with water*. Confining pressure was cycled again.
- Movement of piston in the sand pre-hydrate formation is larger than post hydrate
- Sample was repacked, experimental duplicate of shift in new hydrate experiment (new sand pack) shows similar results

*Lei, L., et al. (2019). "Pore habit of methane hydrate and its evolution in sediment matrix – Laboratory visualization with phase-contrast micro-CT." Marine and Petroleum Geology **104**: 451-467.

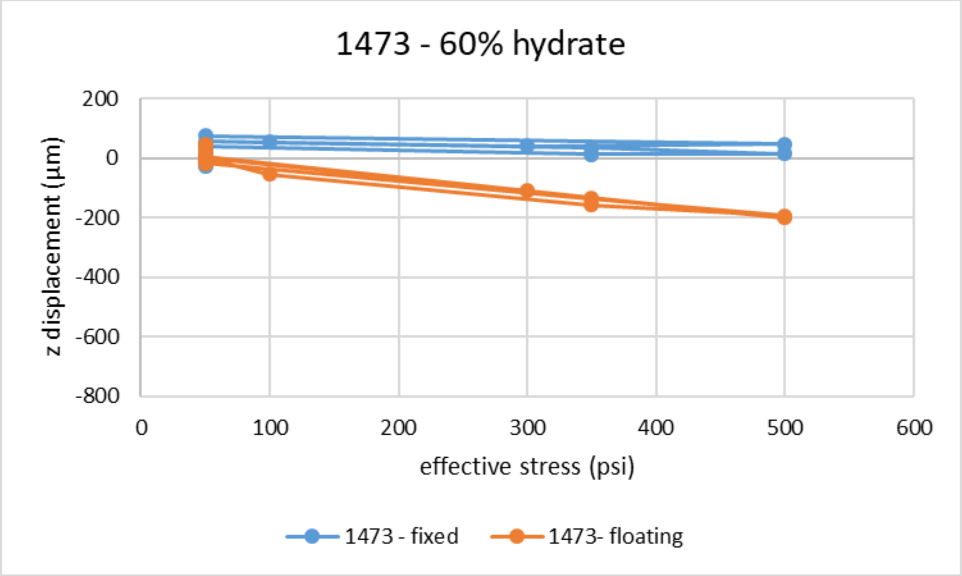
Terzaghi cementing hydrate – 60% saturation

- Sample consisted of sand with 60% water saturation
- Pore pressure 550 psi, confining 600 psi, 2° C. After hydrate formation sample was saturated with water*.
- Confining pressure was cycled from effective stress of 50psi to 500 psi. 60% saturation with hydrate shifted more than 30% case
- Sample was dissociated and effective stress was cycled again.
- After dissociation, shifting of piston was significantly greater.
- As with the 30% water saturation condition, piston movement was observed during dissociation

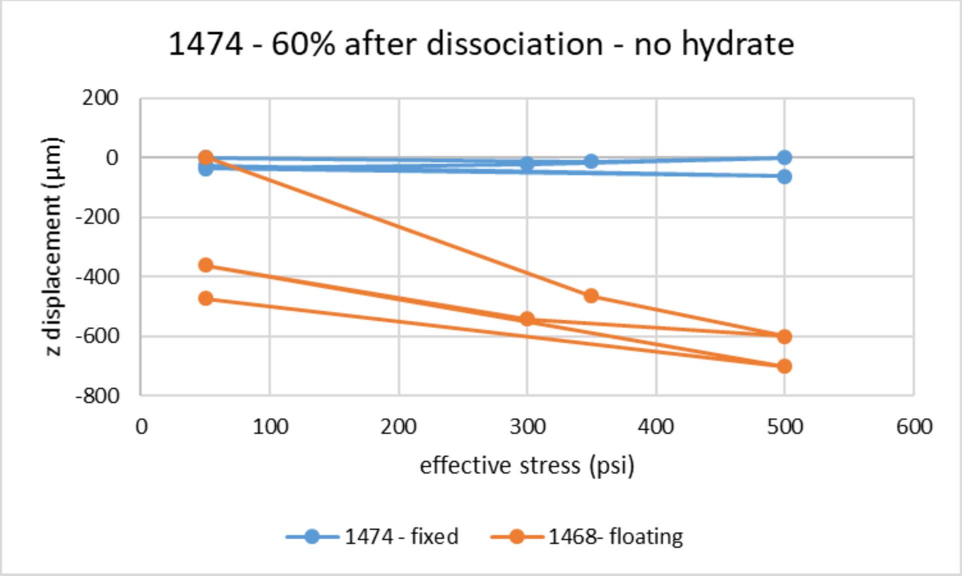
Piston shift (μm) for different experimental conditions

Effective stress psi	30% pre hydrate	30% hydrate - 1	30% hydrate - 2 μm	60% hydrate	60% post hydrate
50	0	2	0	0	2.4
100	-30	64	62	55	
300	126	96	95	11	540
350		94	104	136	464
500	273	152	163	197	650
50 dissoc		126	128	47	

After hydrate formation



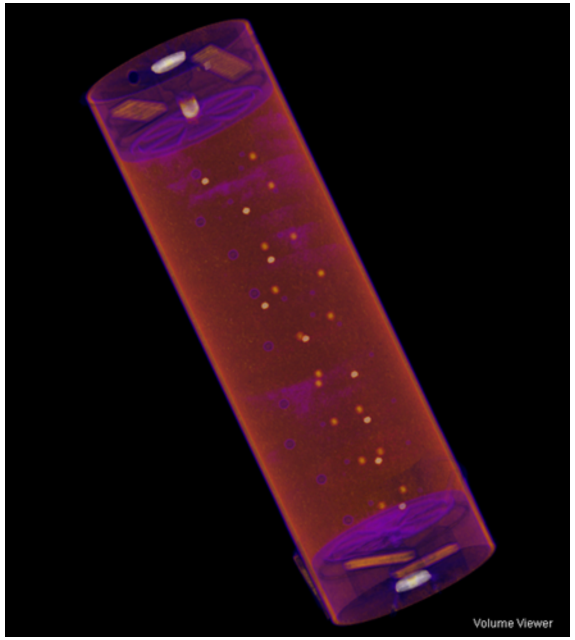
After hydrate dissociation

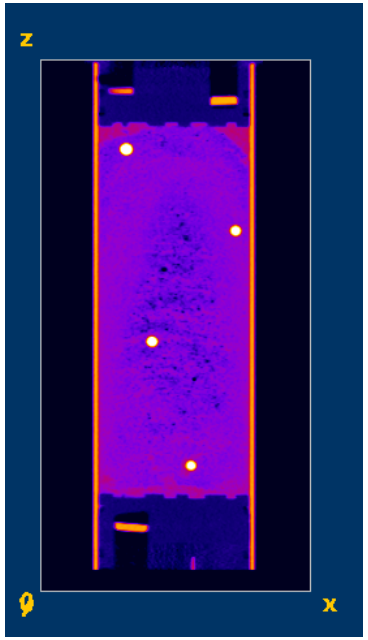


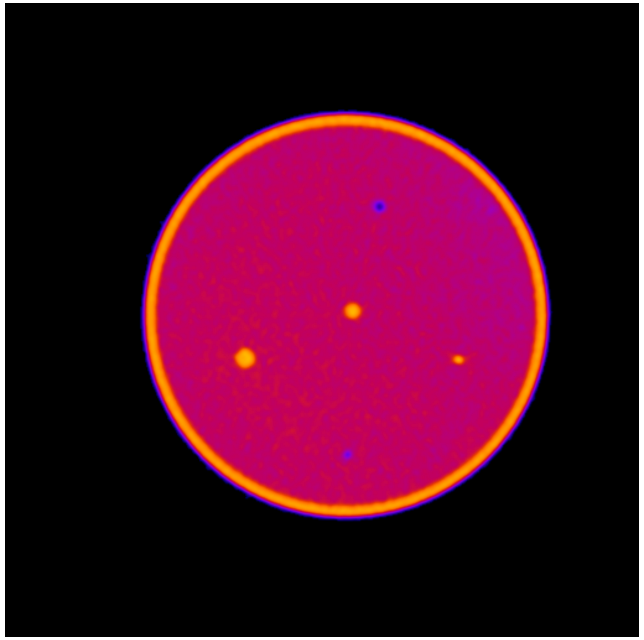
Issues

1. Tracking consolidation throughout the sample
2. Type of hydrate (cementing, pore filling)
3. Hydrate as a more significant part of the porous medium frame

Further Analysis of Compaction – Tracking Consolidation

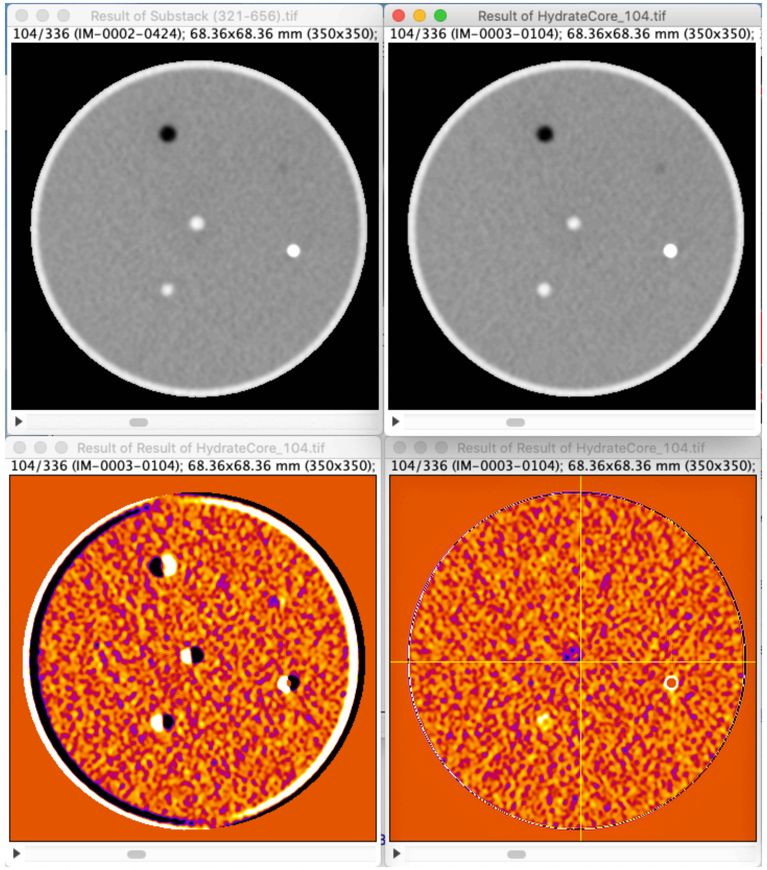






- Since the sliding piston only measured compaction of the end of the sample, spheres of various materials with different densities were placed throughout the sample to monitor changes in compaction along the sample.
- Analysis is ongoing for the quantitative measurement of the movement of these spheres for the 30% water saturation and 60 % water saturation experiments.

Tracking Consolidation – Tracer Method

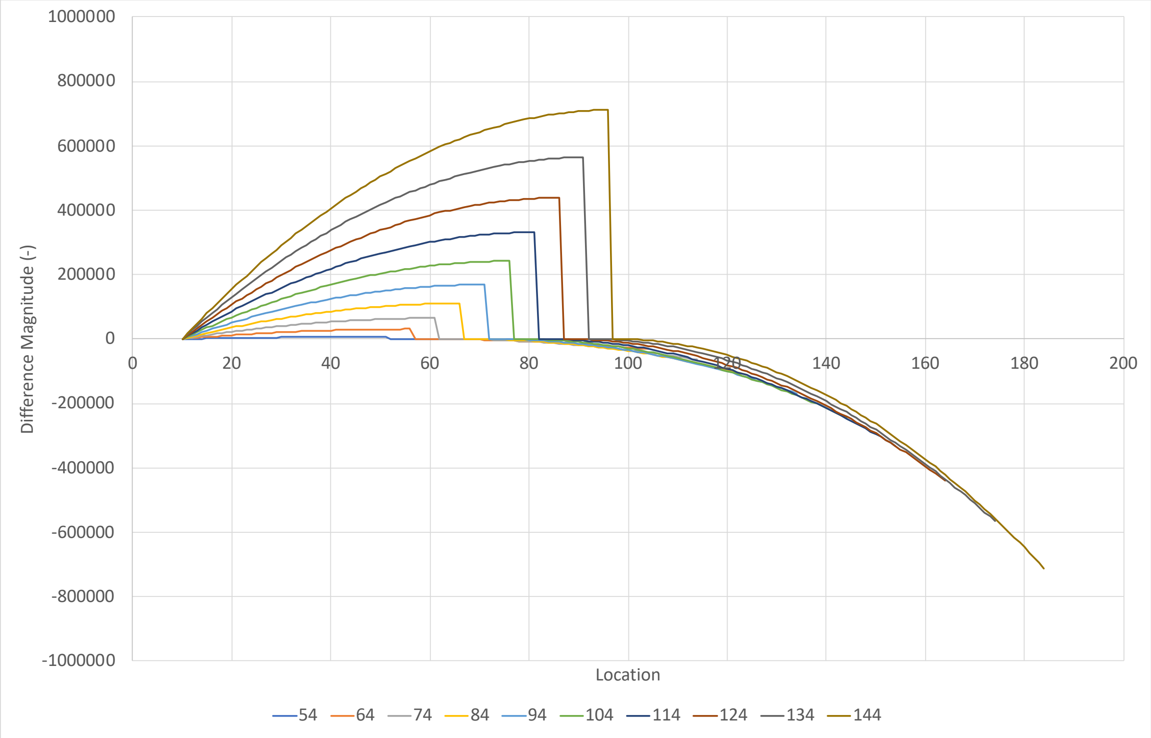


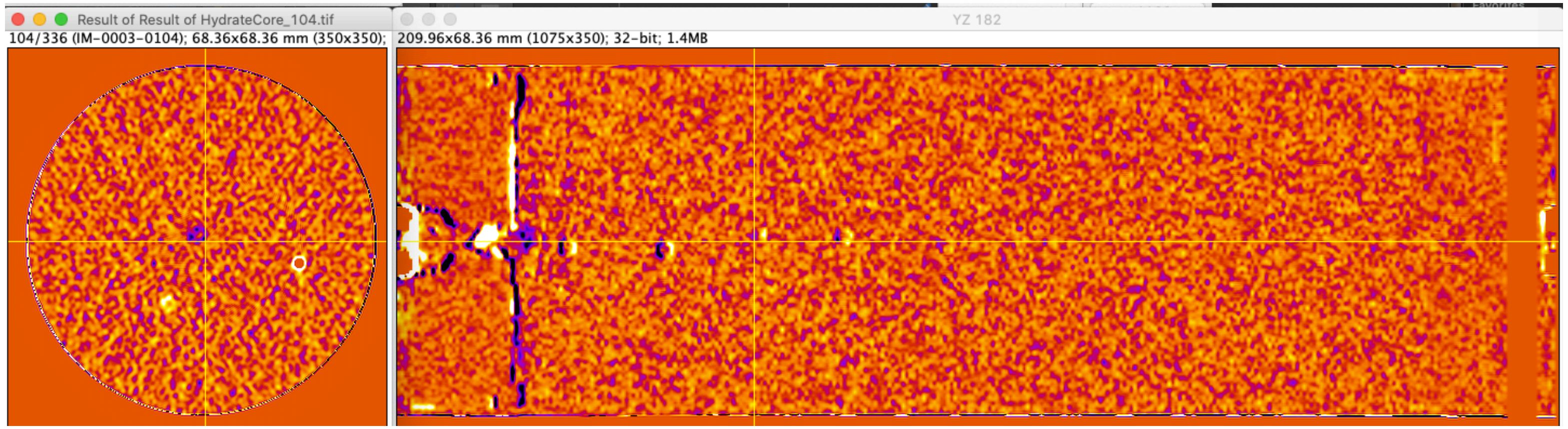
Initial

Final

Unregistered Difference

After Precise Registration

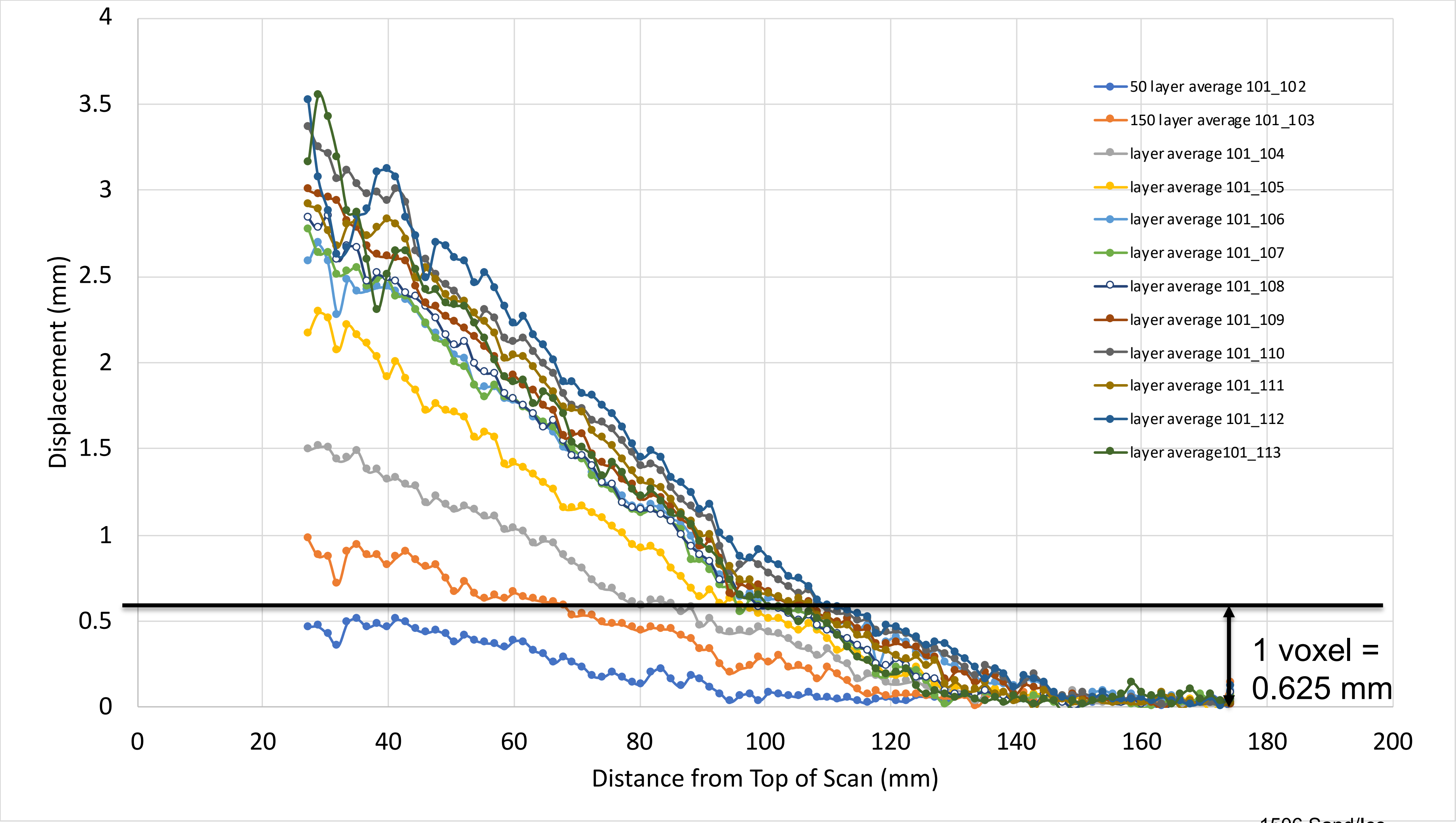




Method needs improvement for efficient implementation!

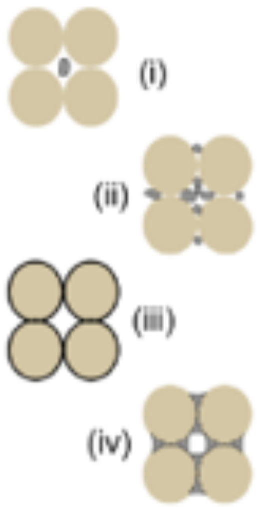
PIV for sub-voxel displacement quantification

Particle Image Velocimetry – compares 2 images and quantifies displacements

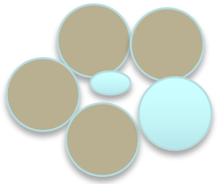


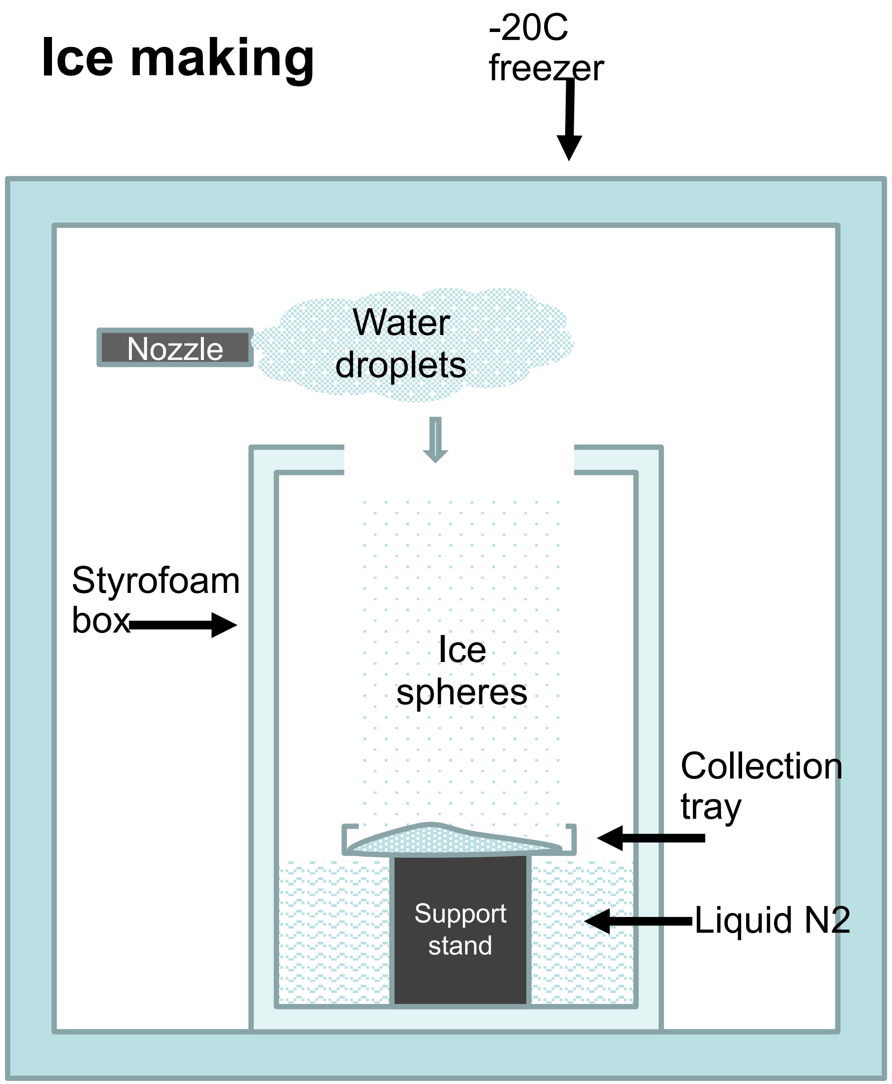
1506 Sand/Ice

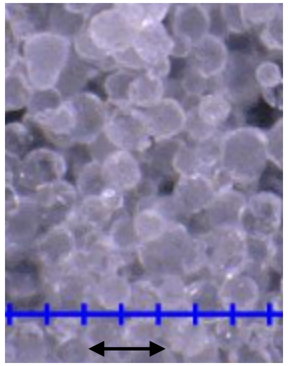
Sample prep for pore filling hydrate



From Madhusudhan et al, 2018



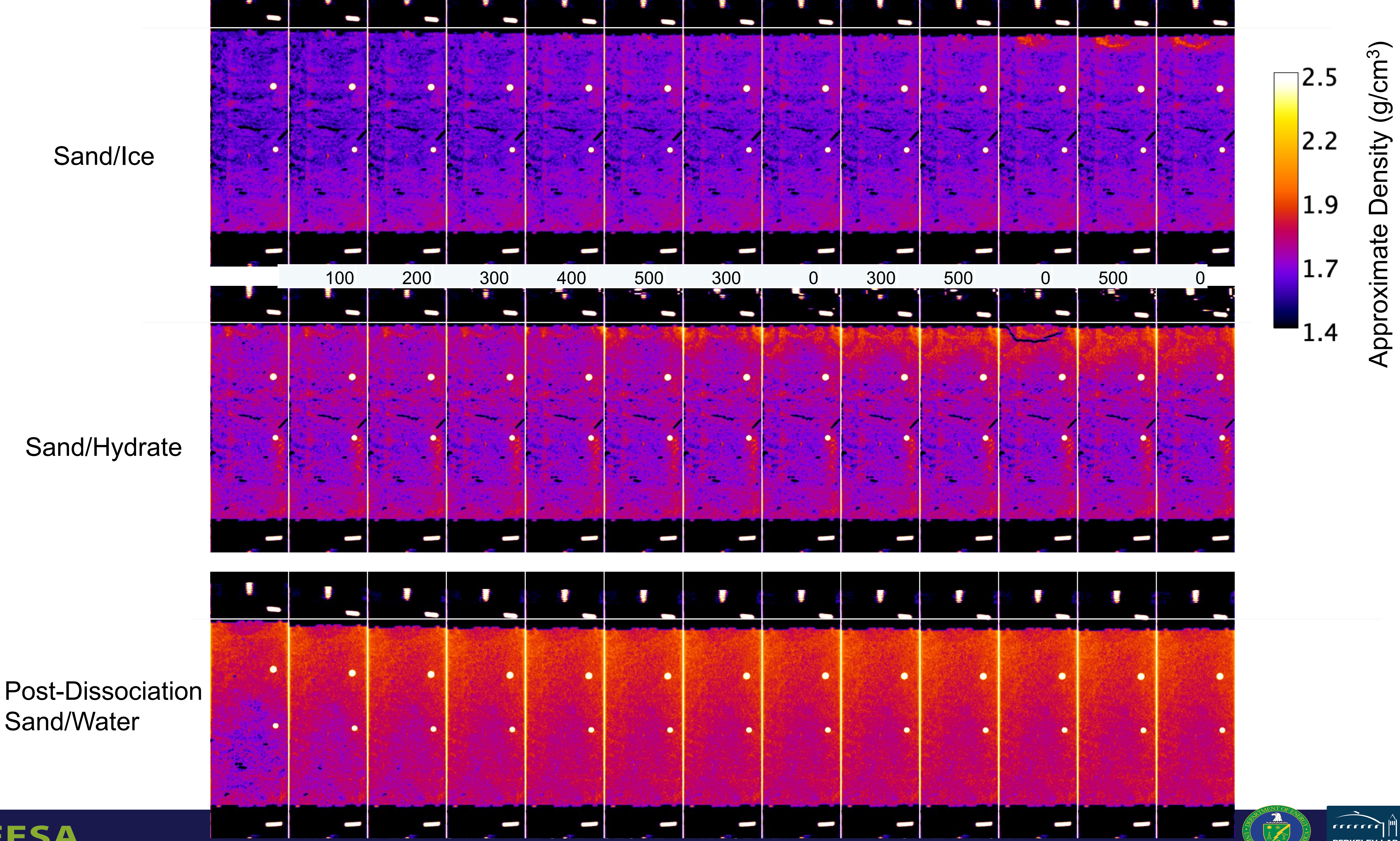


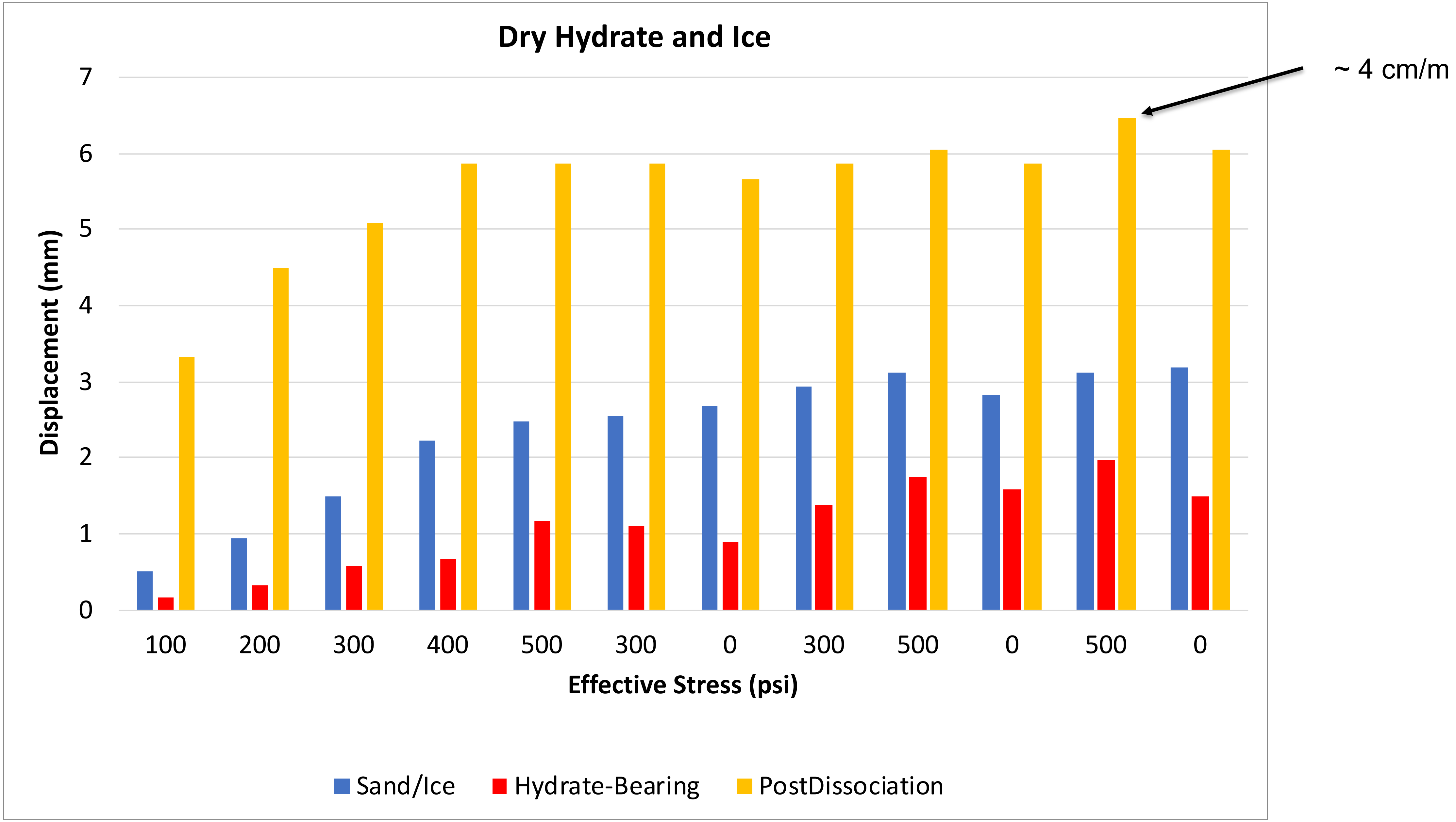


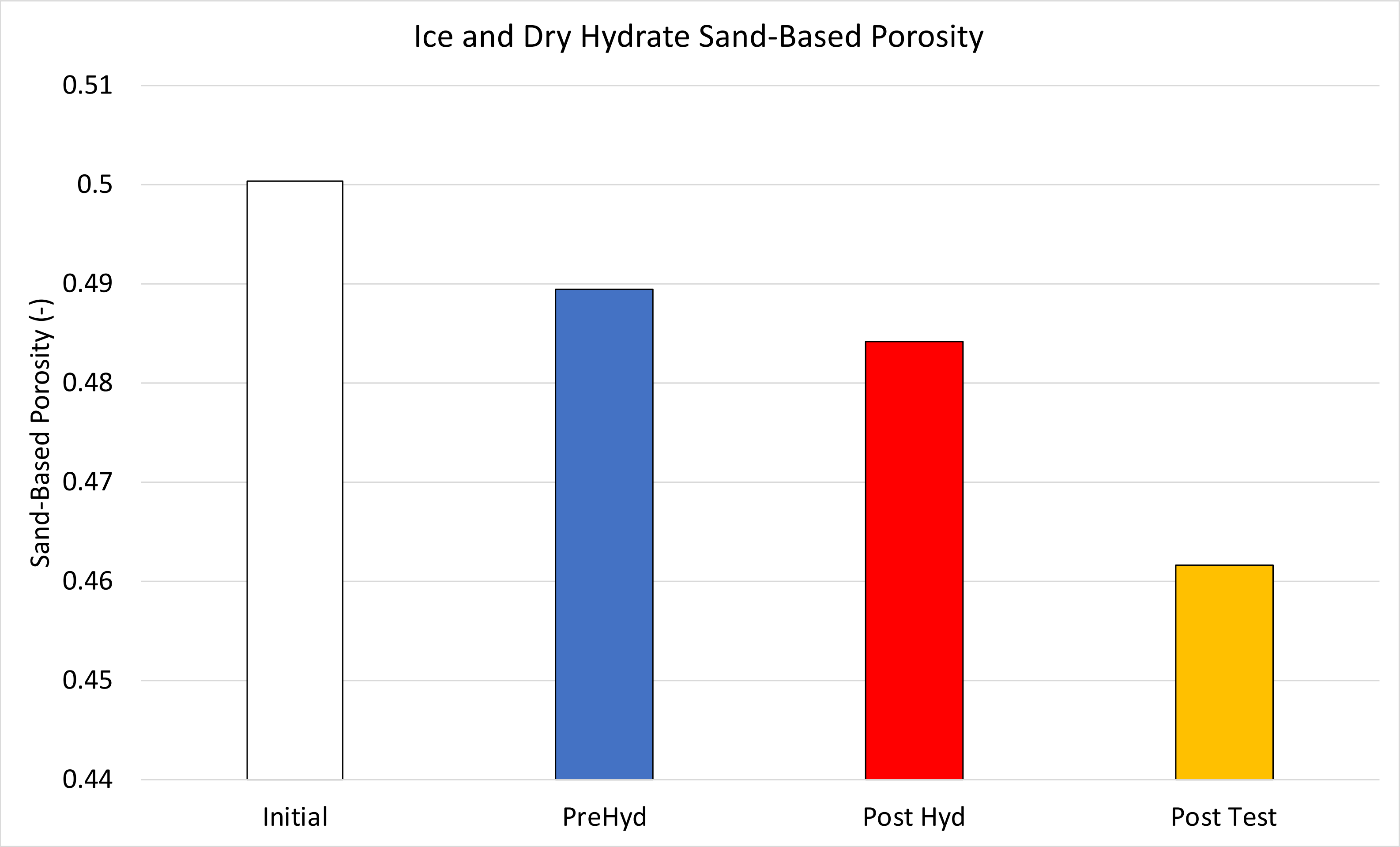
100 um

1. Ice was made by freezing water droplets over liquid N2
2. All components of the system were chilled to -20C, including sand, pressure vessel, sleeve, confining fluid, packing tools.
3. Sand was mixed with ice, sieved through 1 mm sieve to remove potential large ice aggregates.
4. Sand/ice mixture was added in layers with intermediate tamping. (like packing powder)

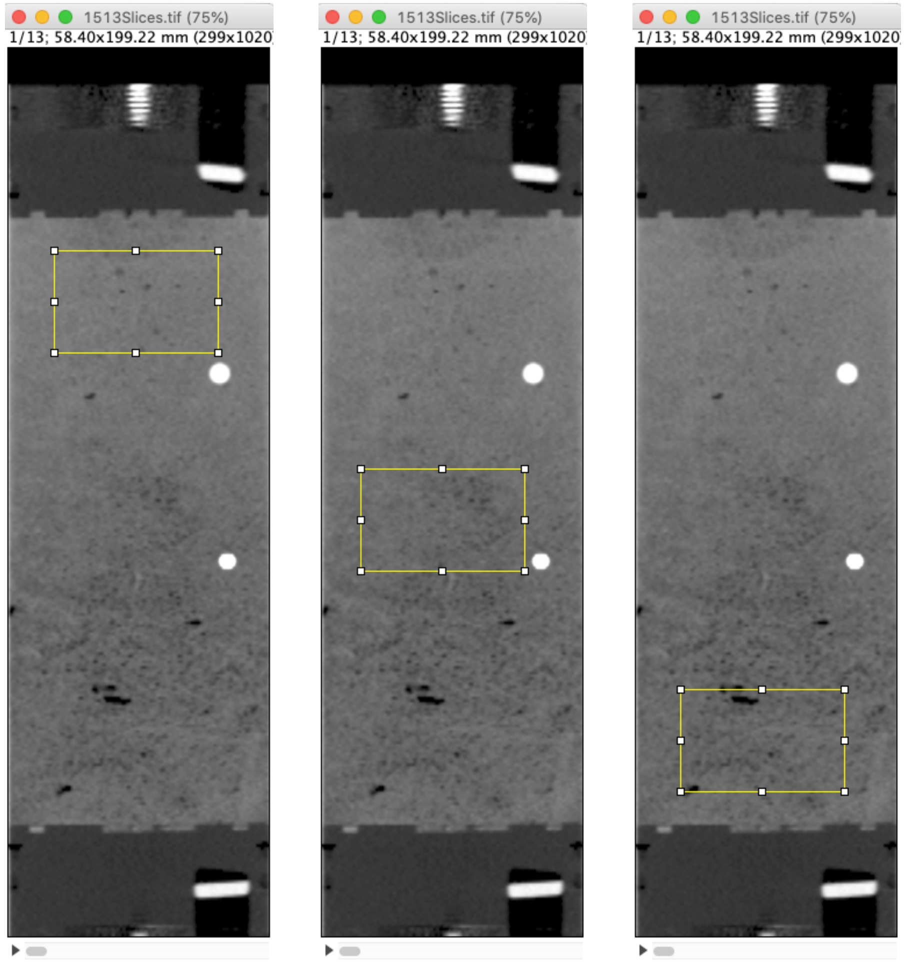
Ice and Dry Hydrate



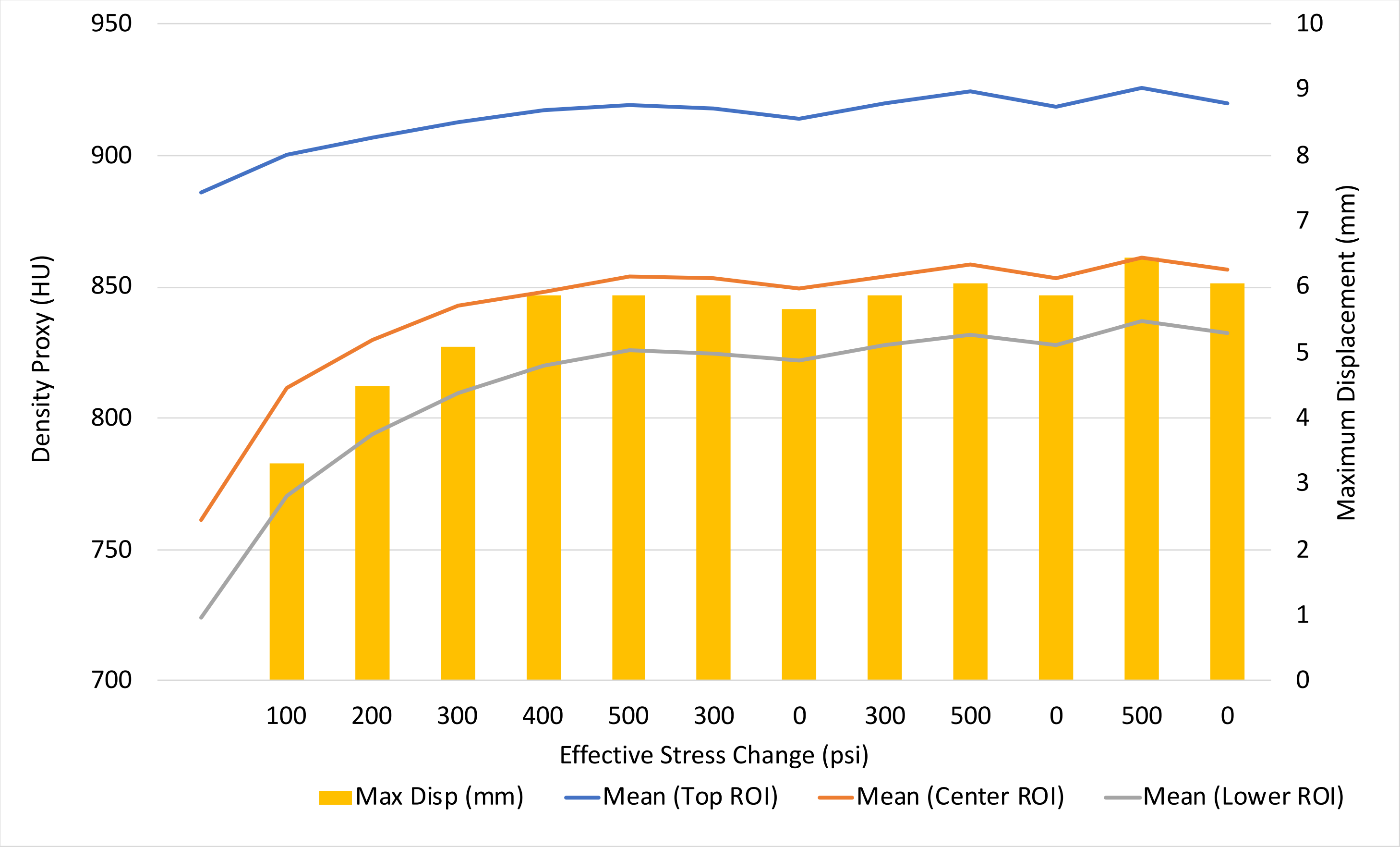

Dry Hydrate and Ice
~ 4 cm/m
7
6
5
4
3
2
1
0
Displacement (mm)
100
200
300
400
500
300
0
300
500
0
500
0
Effective Stress (psi)
Sand/Ice
Hydrate-Bearing
PostDissociation



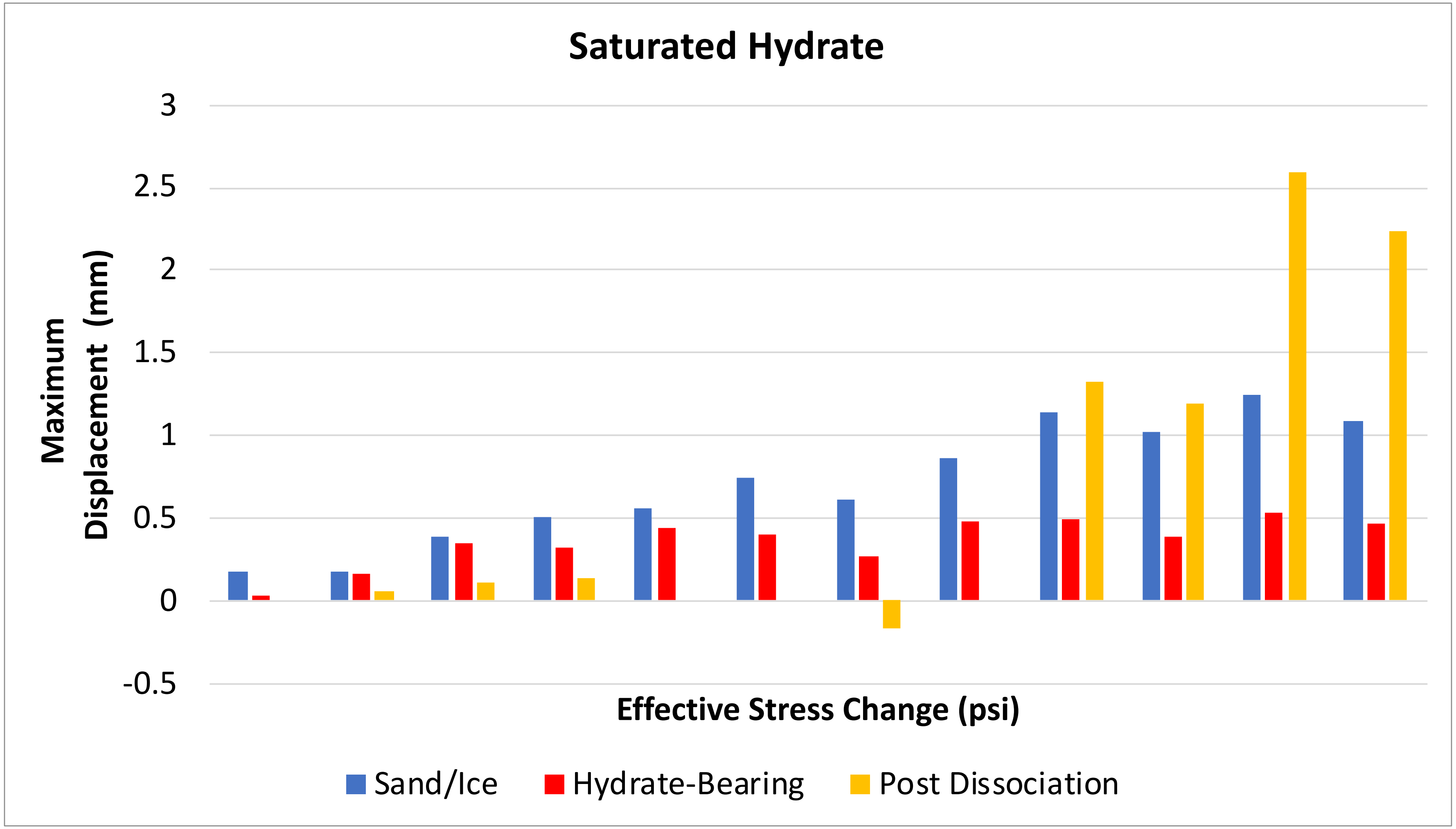
Ice and Dry Hydrate Sand-Based Porosity
Sand-Based Porosity (-)
0.51
0.5
0.49
0.48
0.47
0.46
0.45
0.44
Initial
PreHyd
Post Hyd
Post Test



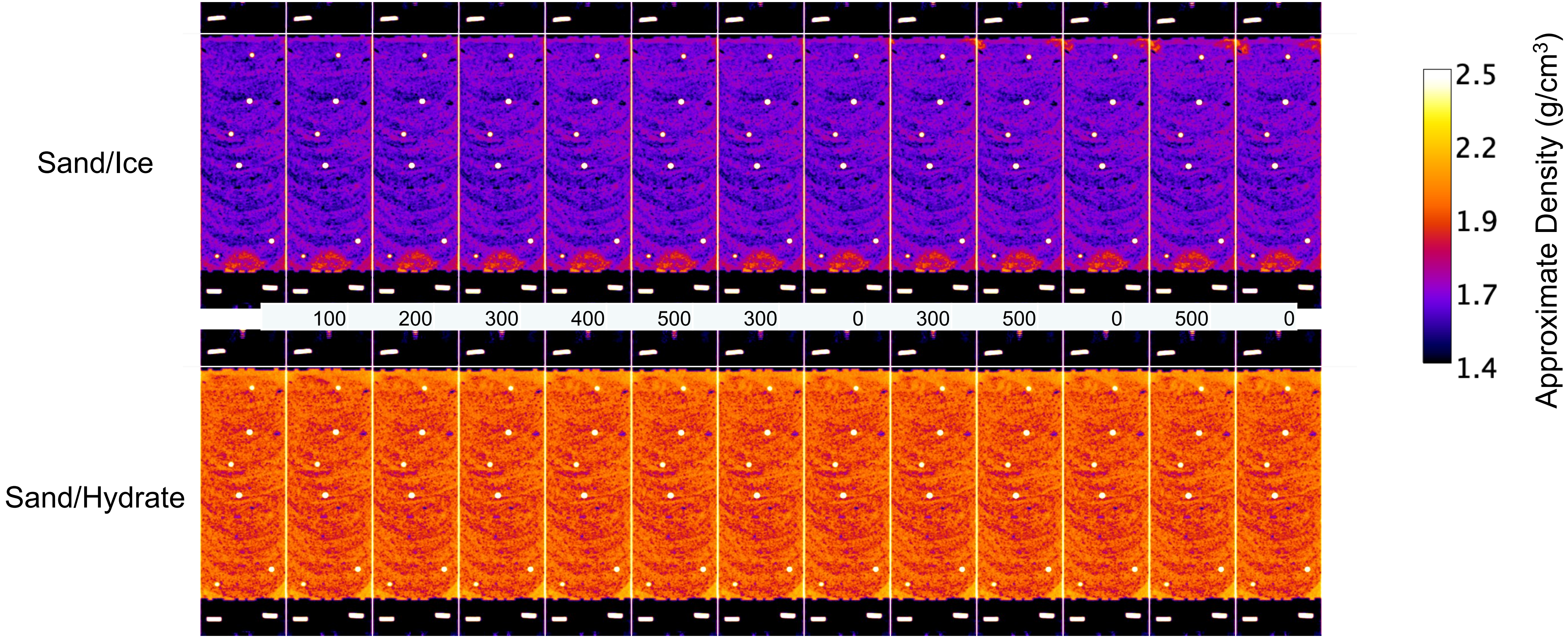
1513Slices.tif (75%)
1/13; 58.40x199.22 mm (299x1020
1513Slices.tif (75%)
1/13; 58.40x199.22 mm (299x1020
1513Slices.tif (75%)
1/13; 58.40x199.22 mm (299x1020



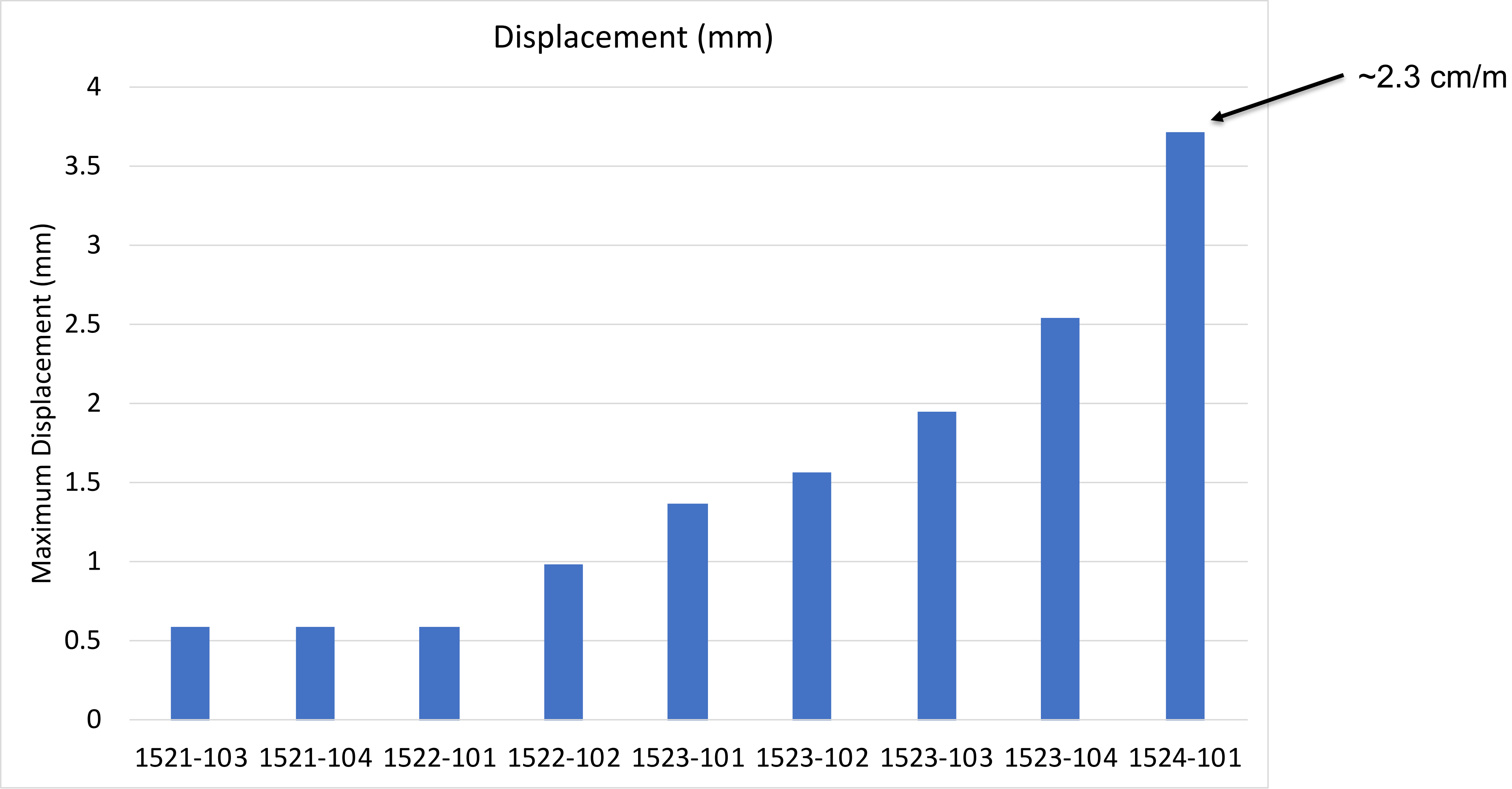
Density Proxy (HU)
950
900
850
800
750
700
Maximum Displacement (mm)
10
9
8
7
6
5
4
3
2
1
0
100
200
300
400
500
300
0
300
500
0
500
0
Effective Stress Change (psi)
Max Disp (mm)
Mean (Top ROI)
Mean (Center ROI)
Mean (Lower ROI)


Saturated Hydrate
3
2.5
2
1.5
1
0.5
0
-0.5
Maximum Displacement (mm)
Effective Stress Change (psi)
Sand/Ice
Hydrate-Bearing
Post Dissociation

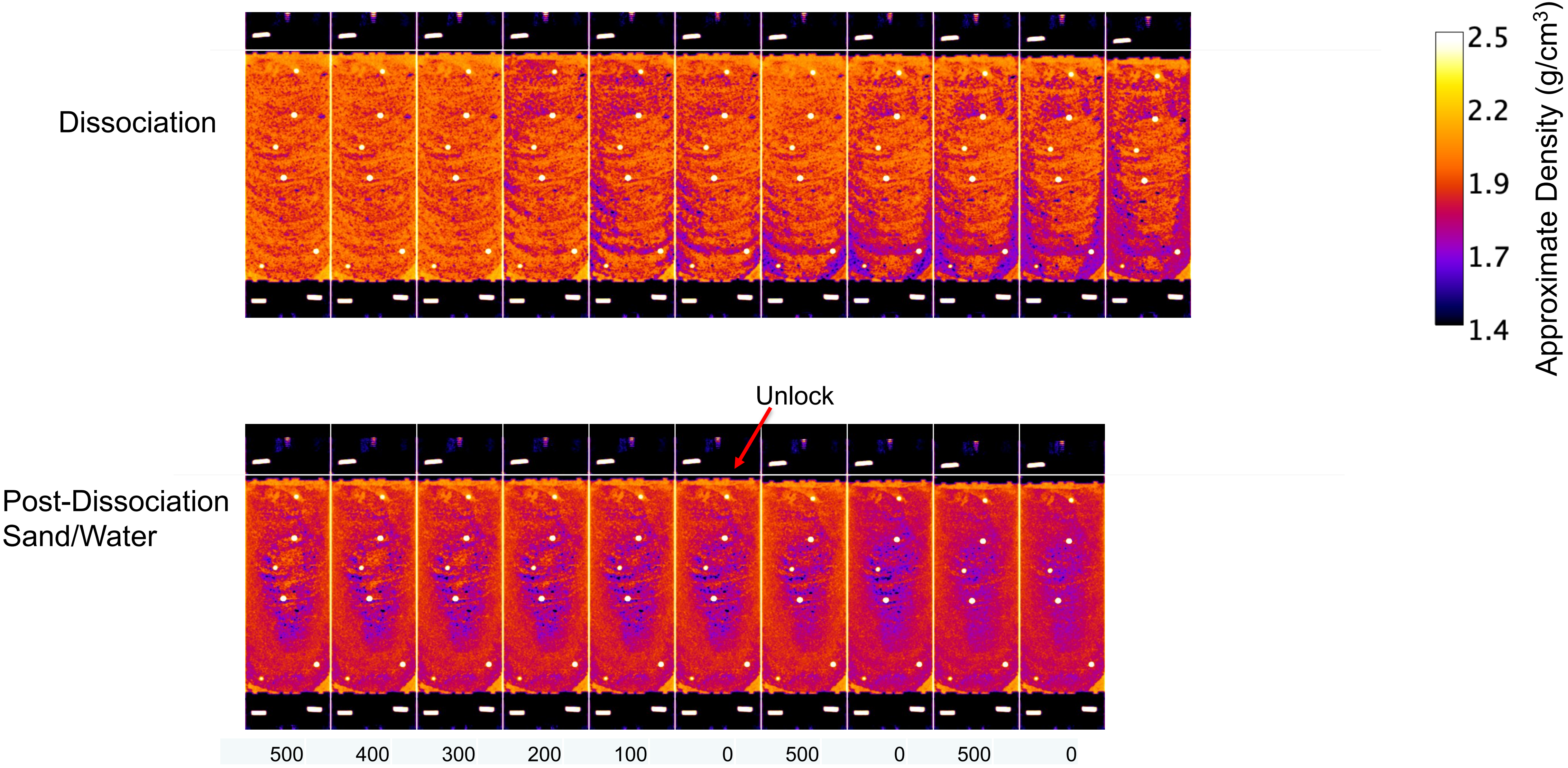
Ice and Saturated Hydrate

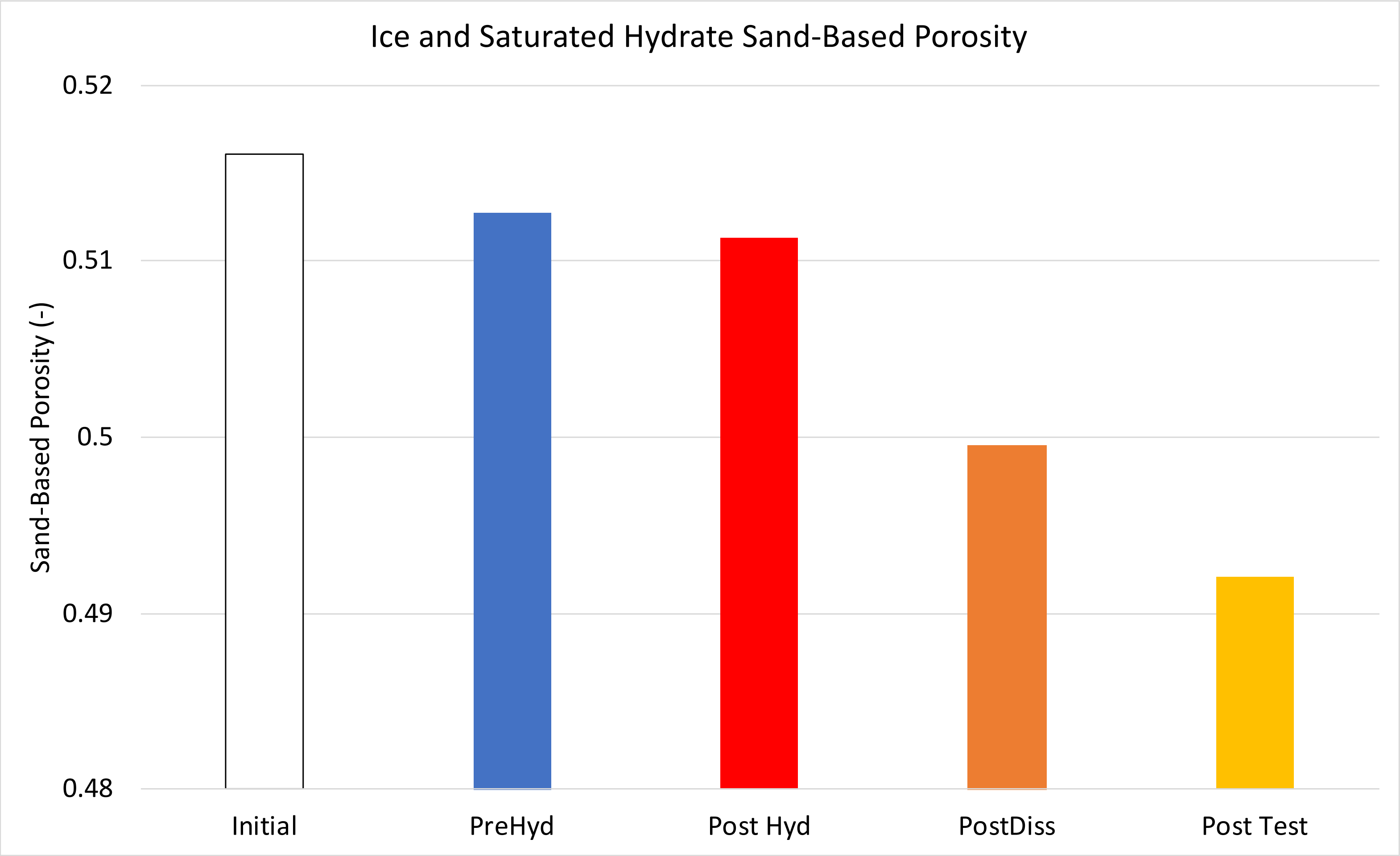


Displacement under 500 psi effective stress during dissociation



Ice and Saturated Hydrate

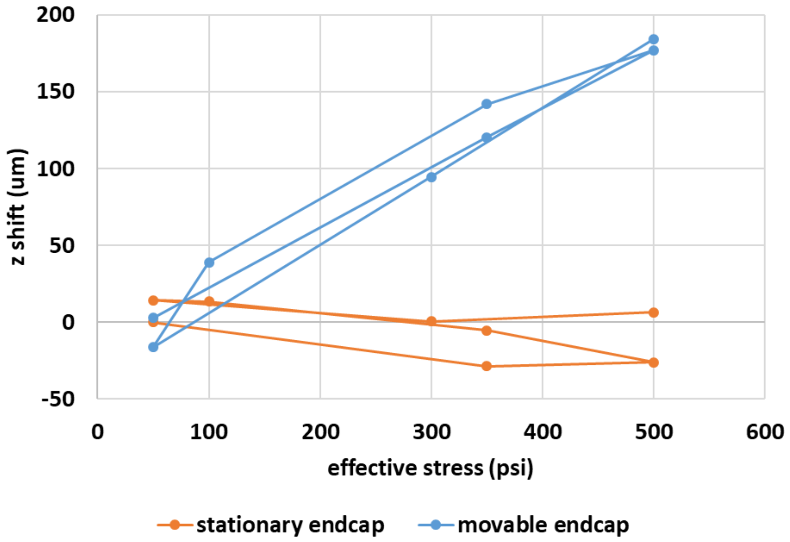



Ice and Saturated Hydrate Sand-Based Porosity
Sand-Based Porosity (-)
0.52
0.51
0.5
0.49
0.48
Initial
PreHyd
Post Hyd
PostDiss
Post Test

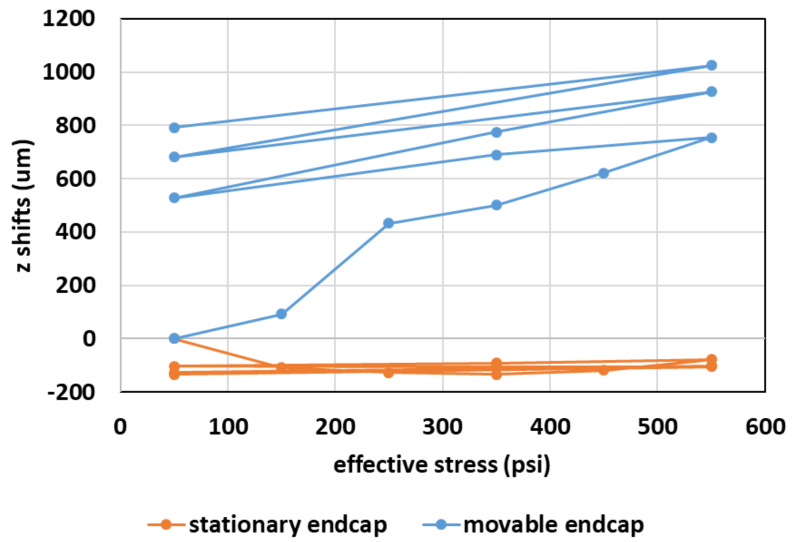
Cementing hydrate

Pore filling hydrate

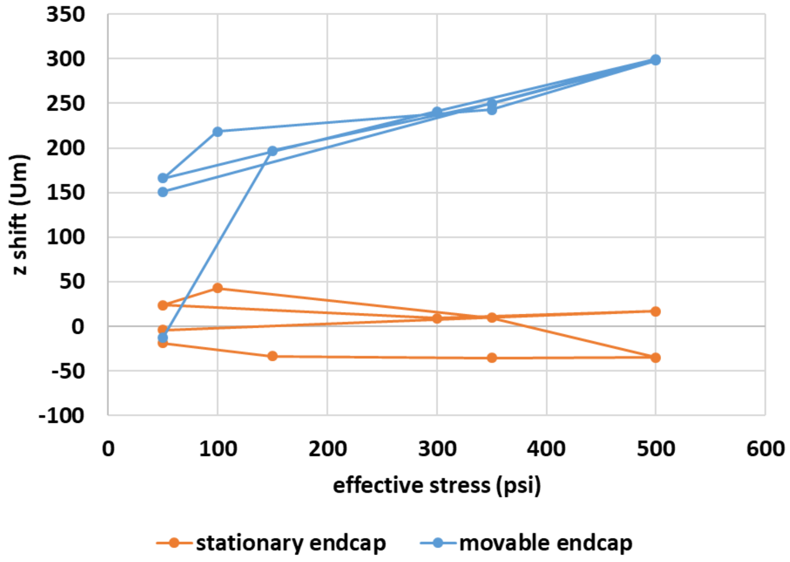
Hydrate present – 60% saturation



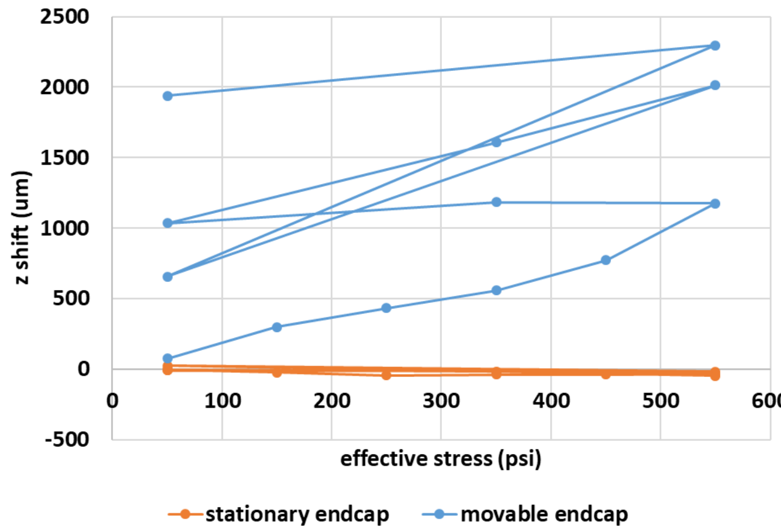
33% hydrate present – water saturated



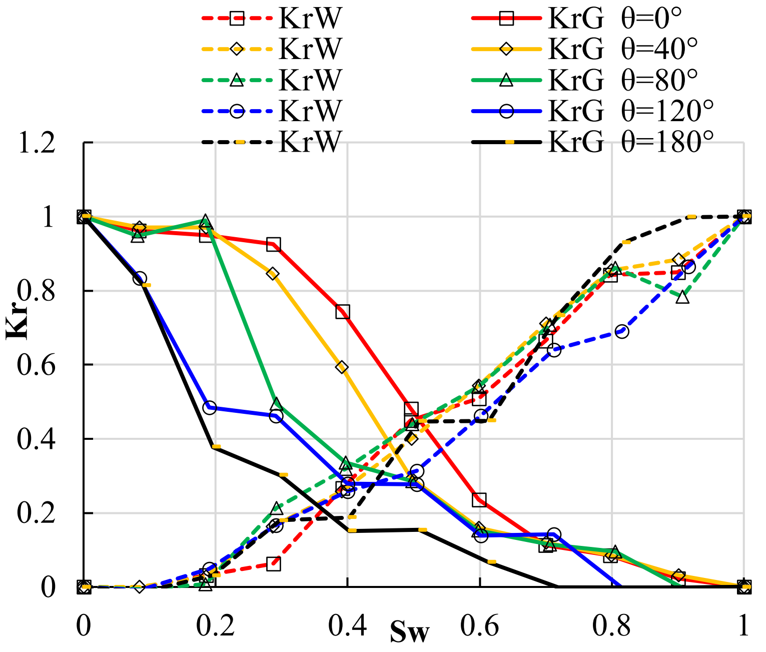
Hydrate present – 30% saturation



36% hydrate present – not water saturated

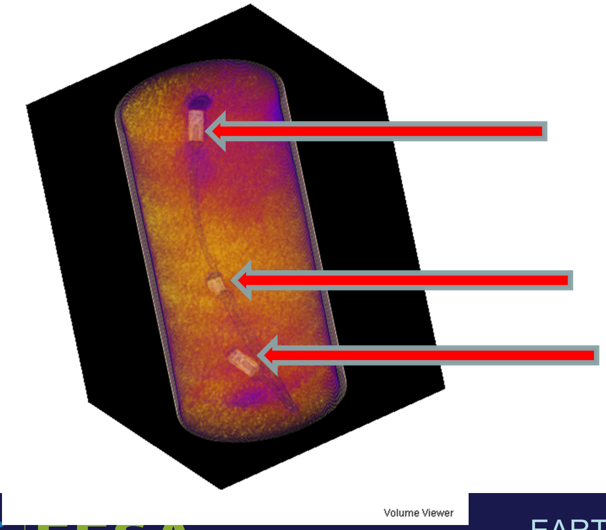


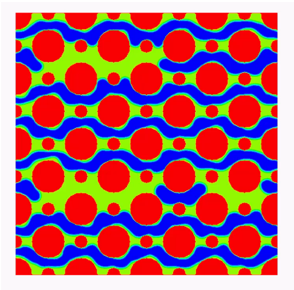
Other Relevant Work



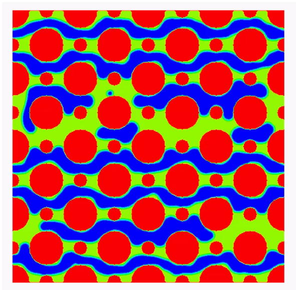
In addition to the above work:

- With TAMU, we devised a method to quantify capillary pressure in hydrate-bearing sediments and demonstrated it.
- In collaboration with TAMU, we aided a student to attempt to measure relative permeability using a newly developed technique. Unfortunately, the technique was accompanied with a number of complications. Although we were not successful with the relative permeability measurements, a positive result was that improvement to approaches in making measurements on hydrate-bearing sediments were made.
- In collaboration with a student from the School of Petroleum Engineering at the China University of Petroleum, East China, we used lattice-Boltzman simulations to investigate relative permeability for grain coating and pore filling hydrate, and mineral wettability.

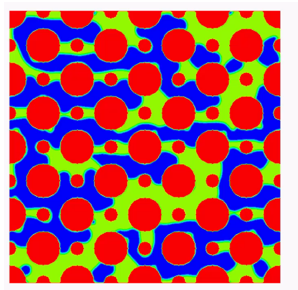




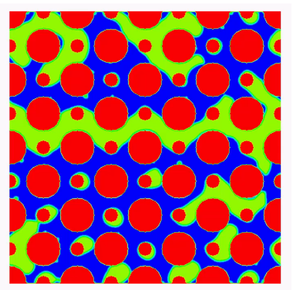
Sw=40%, θ=0°



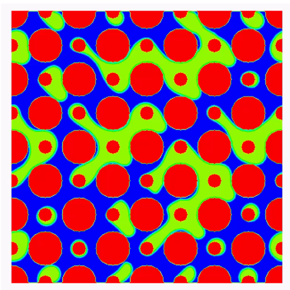
Sw=40%, θ=40°



Sw=40%, θ=80°



Sw=40%, θ=120°



Sw=40%, θ=180°

Blue: Gas

Conclusions, future work

Our funding this year enables us to continue geomechanical evaluation of Alaska Field Test-relevant samples - Measurement of compaction of hydrate-bearing and non-hydrate-bearing sediments under relevant conditions and layered samples.

We seek to capitalize on the improvement of codes and development of numerical models from IGHCC2 and obtain enhanced analysis of the data.