Hydrate-Bearing Core Characterization: Pore to Core Scale Analysis (FWP-1022410)

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Project Overview

Project Goals:

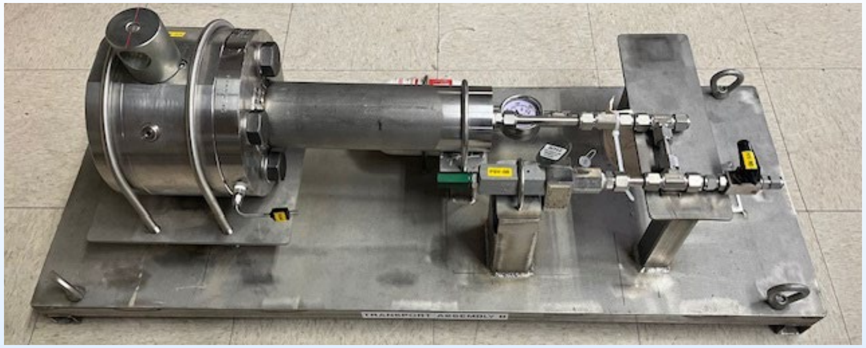
- Determining hydrological (e.g., permeability), geomechanical (e.g., compressibility, mechanical strength), and acoustic properties of preserved hydrate-bearing core samples from ongoing and future field expedition
- Obtaining high resolution X-ray micro-computed tomography (CT) images at in-situ conditions on preserved cores as well as cryogenically preserved cores to determine grain size distribution, hydrate saturation, and geologic textures
- Maintain and improve current capabilities of pressure core characterization and X-ray μ-CT visualizations tools (PCXT)

Outline

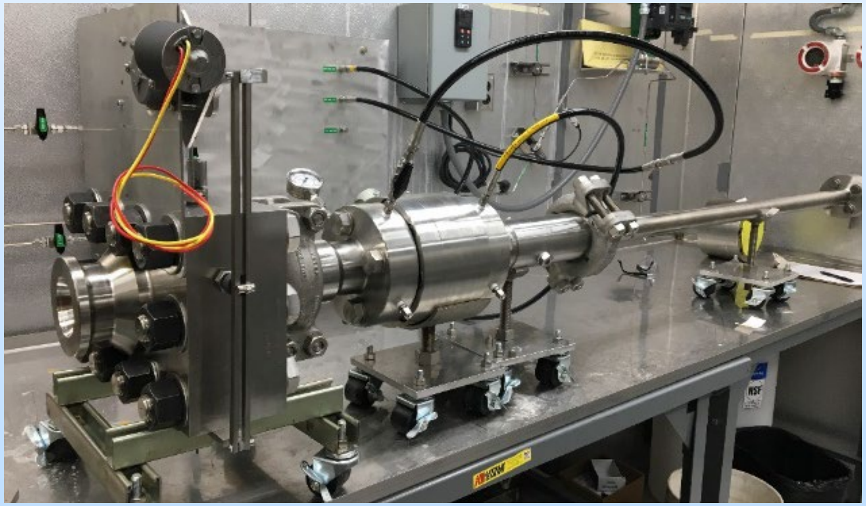
1. Current capability (geomechanical/hydrological property, acoustic property, experimental simulations capability at in-situ condition (P,T))
2. Recent updates
   - New cryo-core handling property, application potential, strength of cryo-core compared to pressure core
   - Added new functionality (LN sprayer, CT scanning, 3D printing for part fabrication)
3. CT visualization
   - new procedures to identify hydrate, calculate hydrate saturation and permeability
4. Further studies
   - Effective Stress Chamber (ESC) and Triaxial Stress Chamber (TSC) with acoustics to estimate geomechanical property/deformation, grain crushing potential, permeability/relative permeability evolution under production condition

Pressure Core

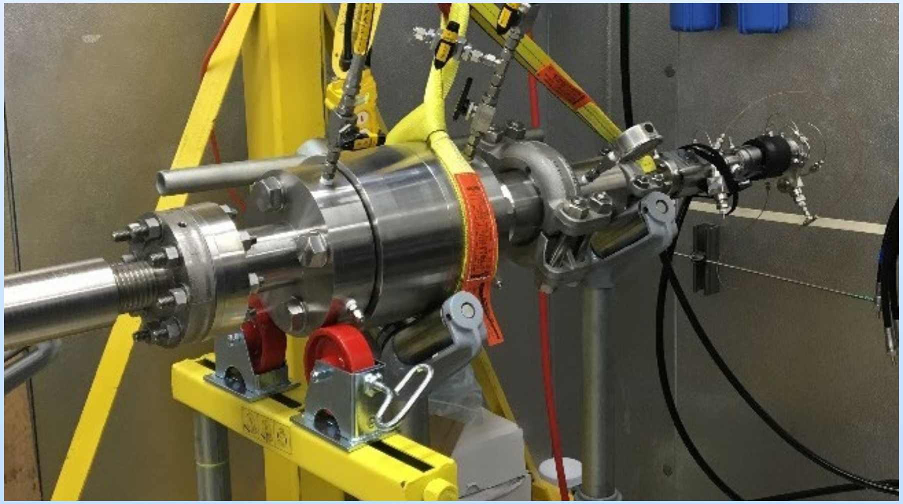
Existing Pressure Core Handling Devices



Transport Chamber
Sample Length:
~1 foot (~30 cm)



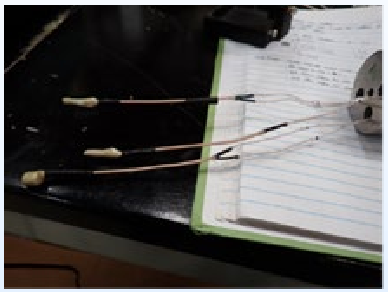
Cutter + Temporary Storage + Manipulator

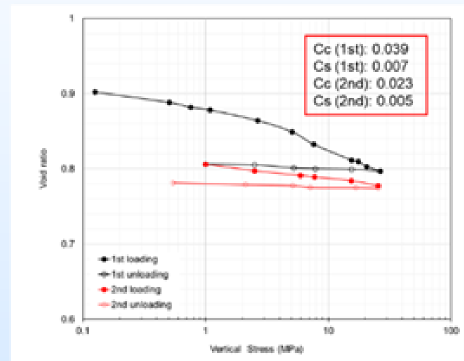


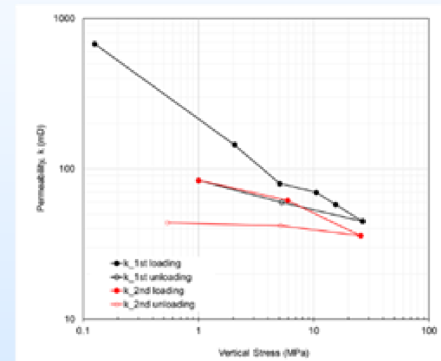
Subsampler for CT

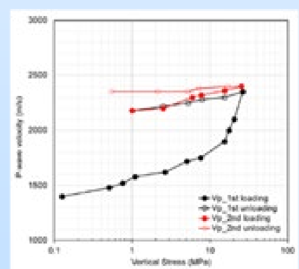
Pressure Core

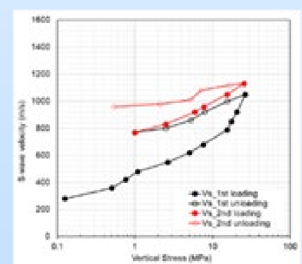
ESC – Effective Stress Chamber

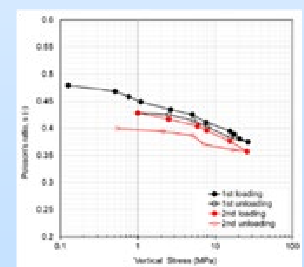












Cryogenic Core

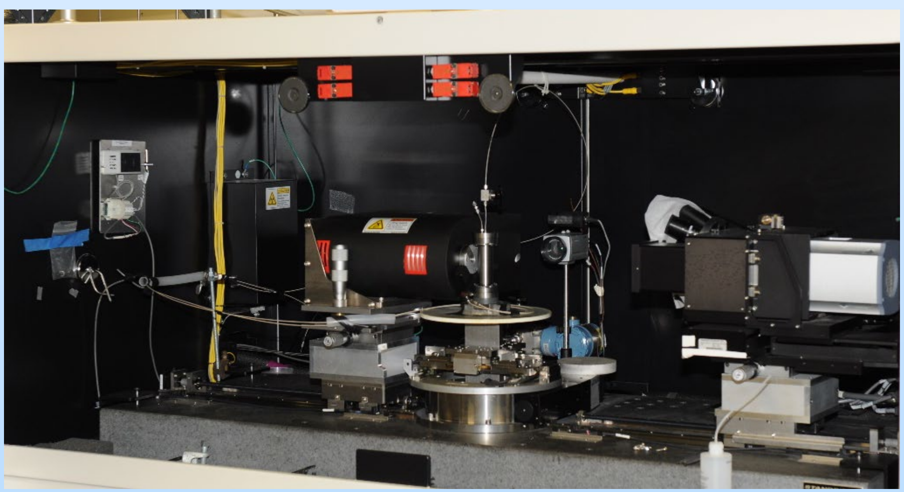
- Unique opportunity to preserve hydrate-bearing sediments

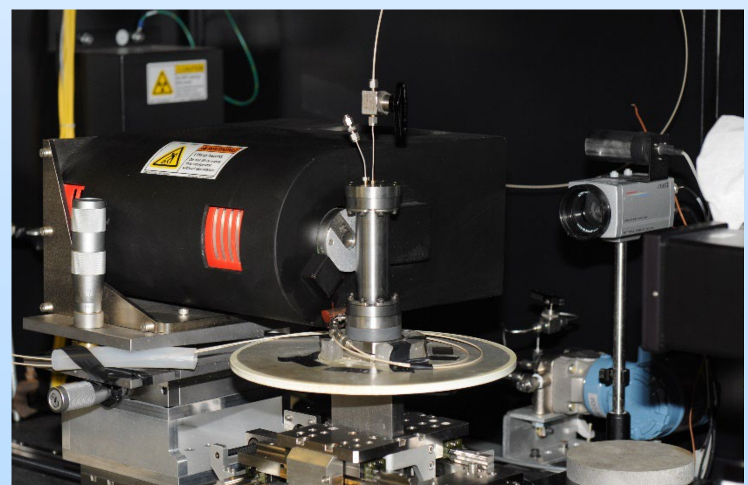
    pressure core -> dumped into liquid nitrogen -> cryogenic core

Can we use cryogenically preserved hydrate-bearing sediment to investigate pore scale characterization of hydrate habits, fluid-matrix interaction, and soil skeleton deformation under excessive stress for linking pore-scale phenomena to larger scale properties

→ Utilizing state-of-the-art CT capabilities at NETL

- μ-CT (~1-2 micron resolution)





Hydrate-Bearing Sediment Samples

- Analysis Capabilities at NETL
  - 4 Pressure Cores
  - 10 Cryogenic Cores

Pressure Core:

~12 inches

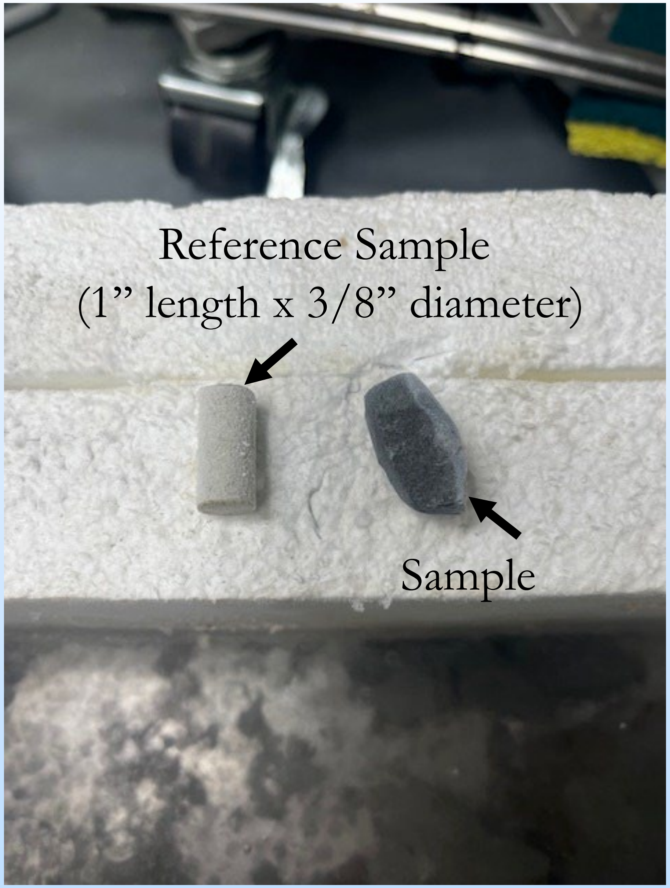
(X-ray scan prior to subsampling)

Cryogenic Core:

~10 inches

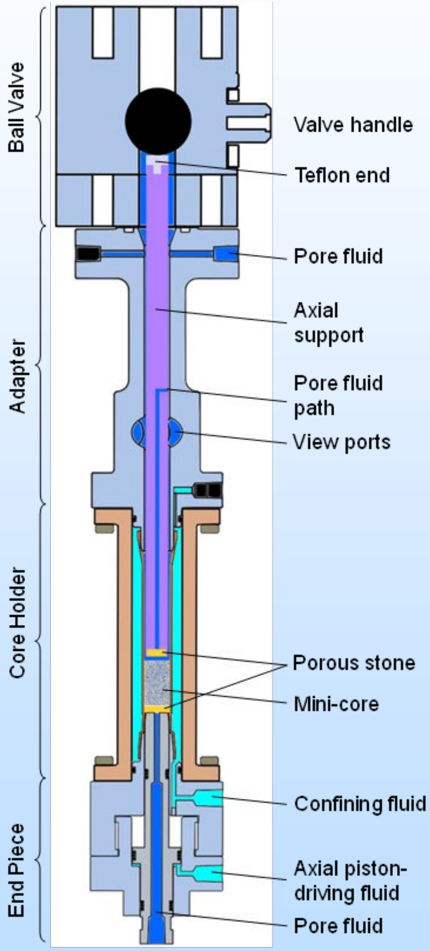
Cryogenic Core

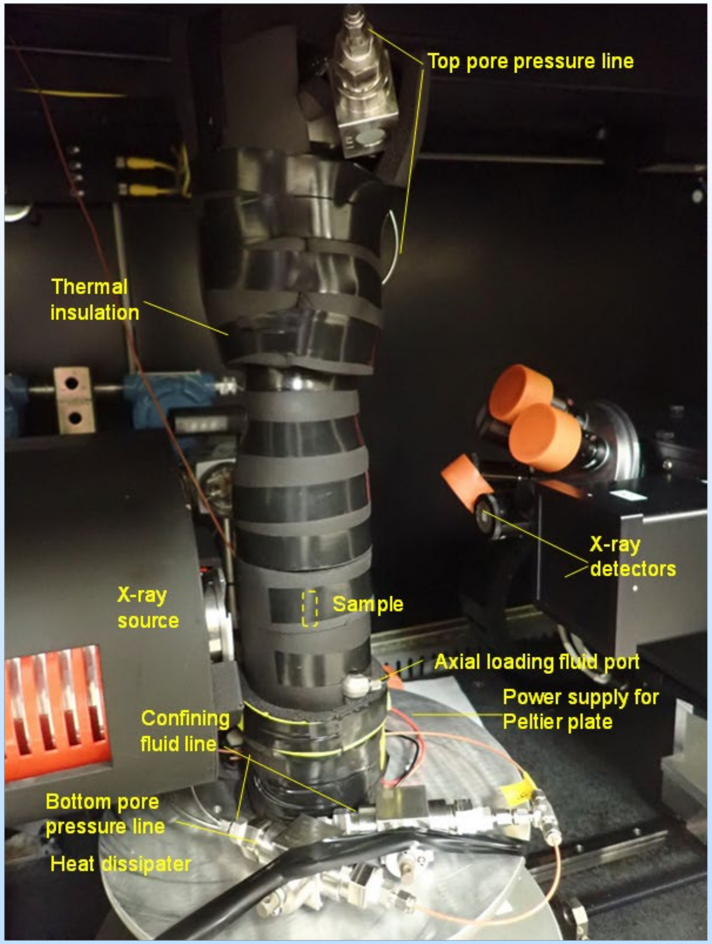
Sample Preparation



Cryogenic Core

μ-CT Imaging



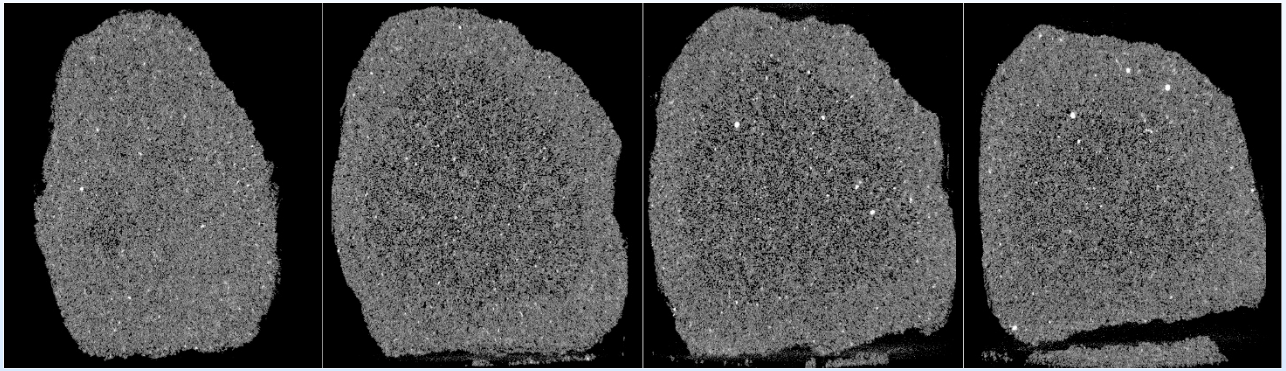


Cryogenic Core

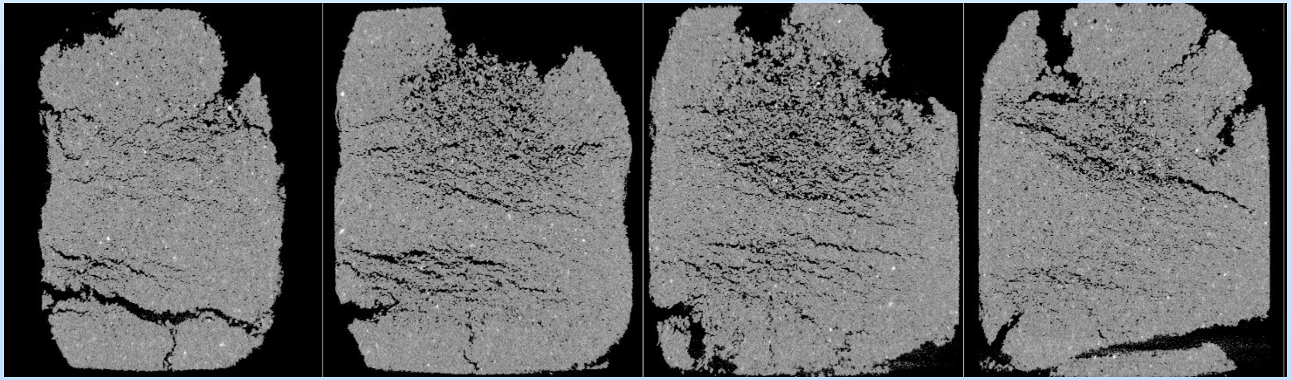
μ-CT Imaging

Low Resolution – 5.8 μm

3,000 psi – 10 ˚C – within hydrate stability



3,000 psi – 22 ˚C – outside hydrate stability

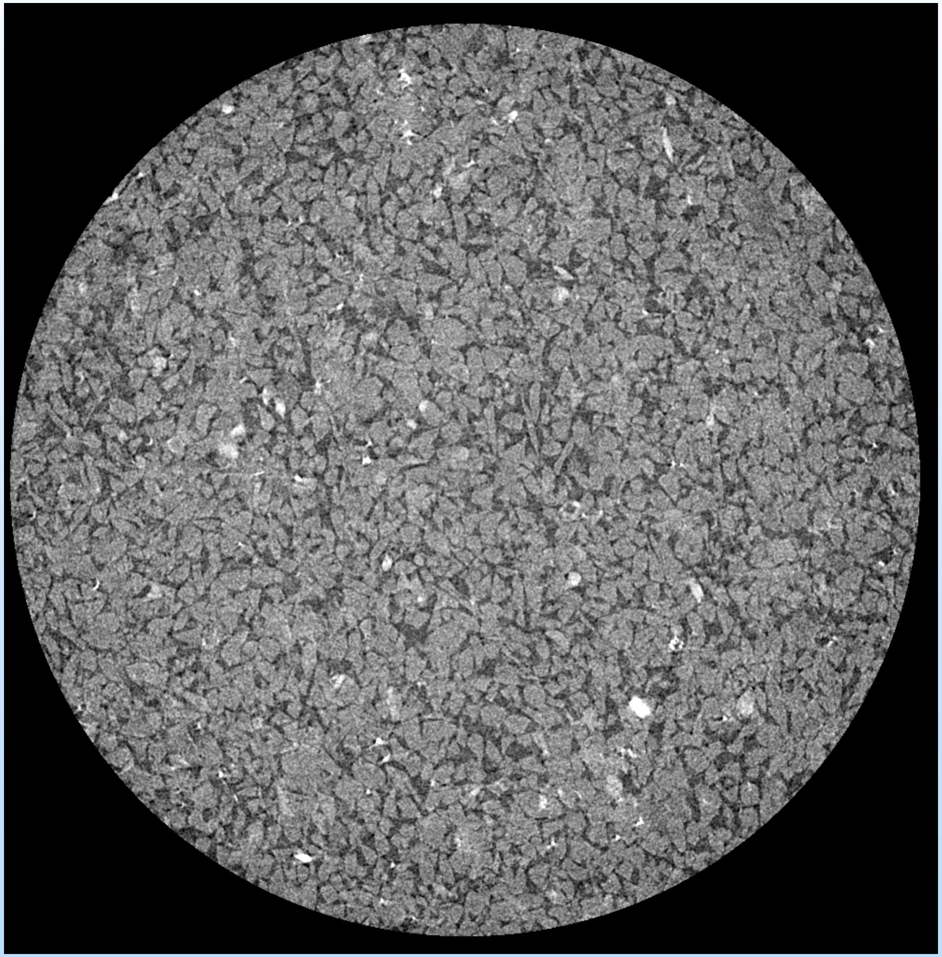


Cryogenic Core

μ-CT Imaging

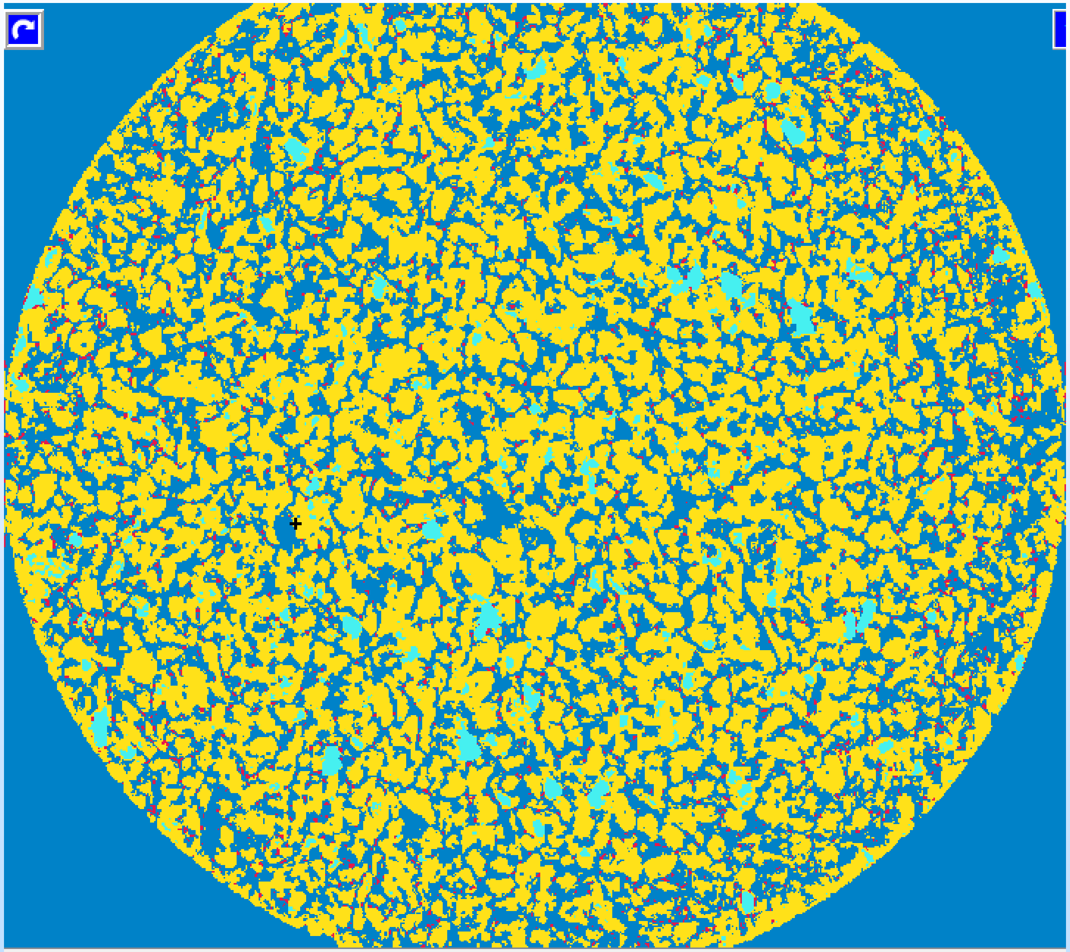
High Resolution – 1.88 μm

3,000 psi – 10 ˚C – within hydrate stability



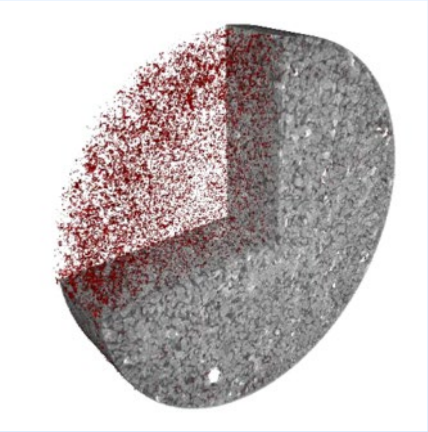
Cryogenic Core

μ-CT Imaging – Image Segmentation (Ilastik)



4 Classes:

- Grains
- Heavy grains
- Pore space
- Oil

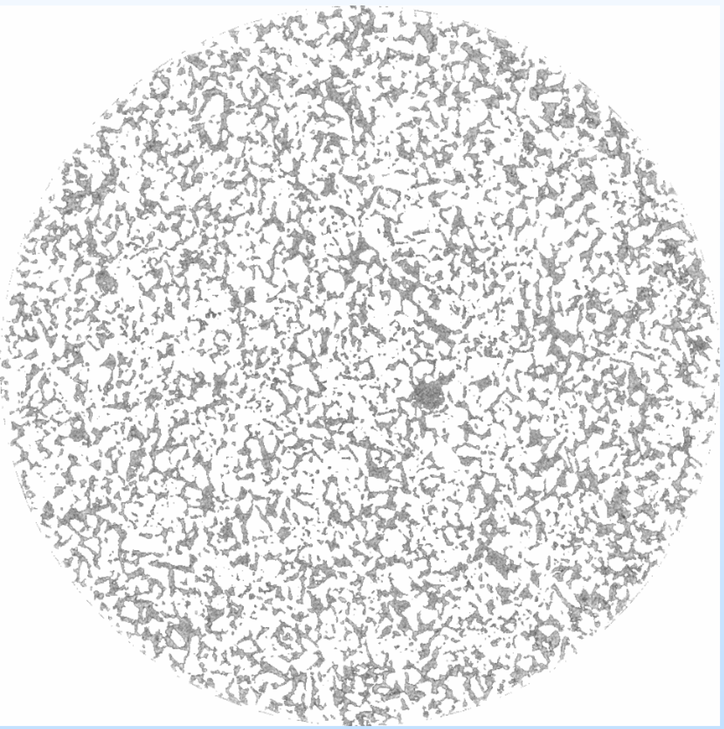


In-situ or oil in place ~ 5%

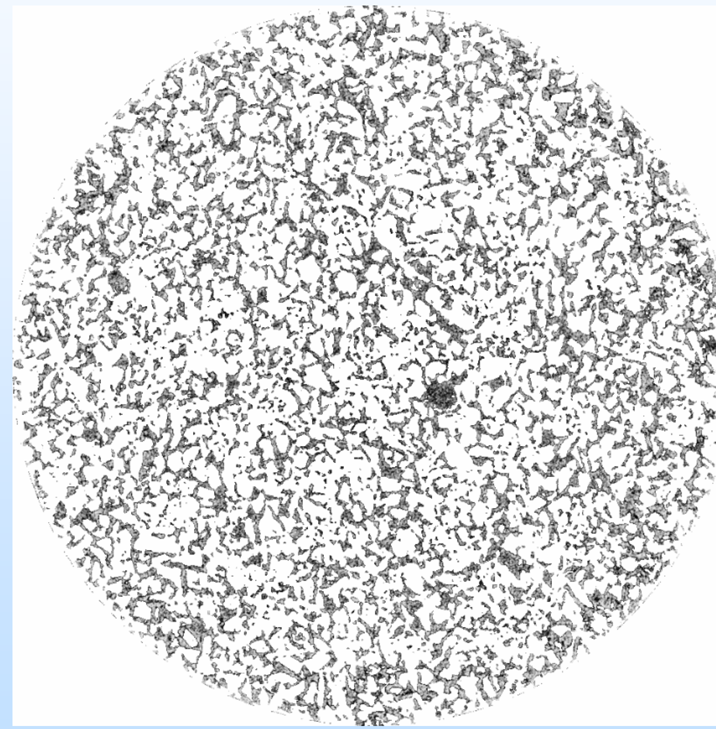
Cryogenic Core

μ-CT Imaging – Image Segmentation (Ilastik)

Segmented pore space was used as a mask on the original image stack
→ This results in only preserving the pore space



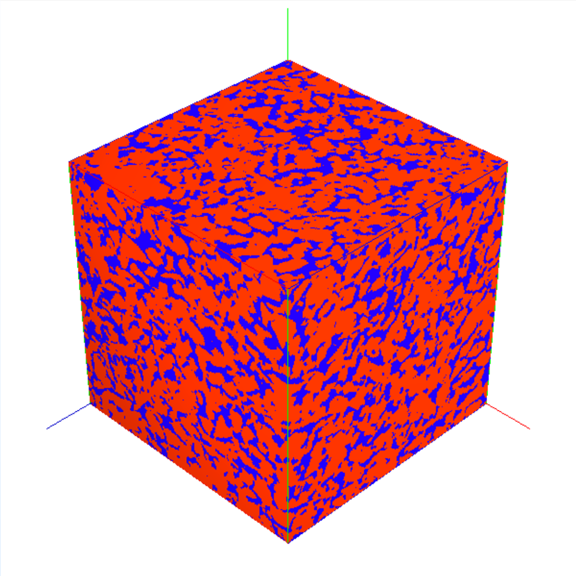
To further enhance the contrast: histogram equalization was used to improve distinction between hydrate and pore fluid
→Darker areas correspond to presence of hydrates



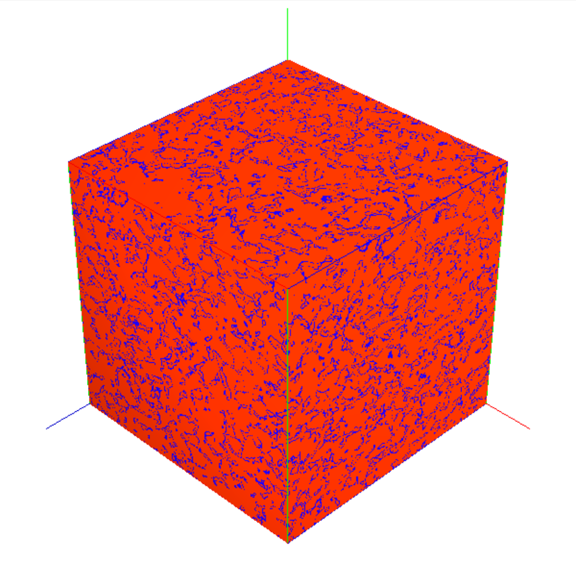
2nd Round of Segmentation: Hydrate Saturation: ~55%

Cryogenic Core

μ-CT Images – Permeability Estimation Using FDSMM Simulator



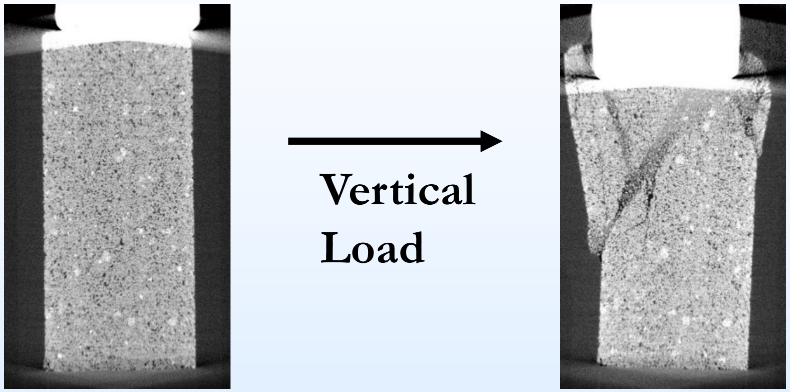
300 x 300 x 300 pixel volume used to determine permeabilities

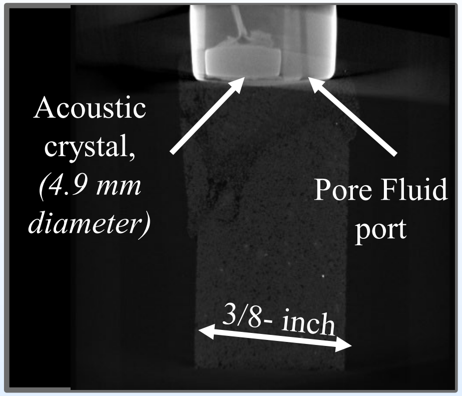


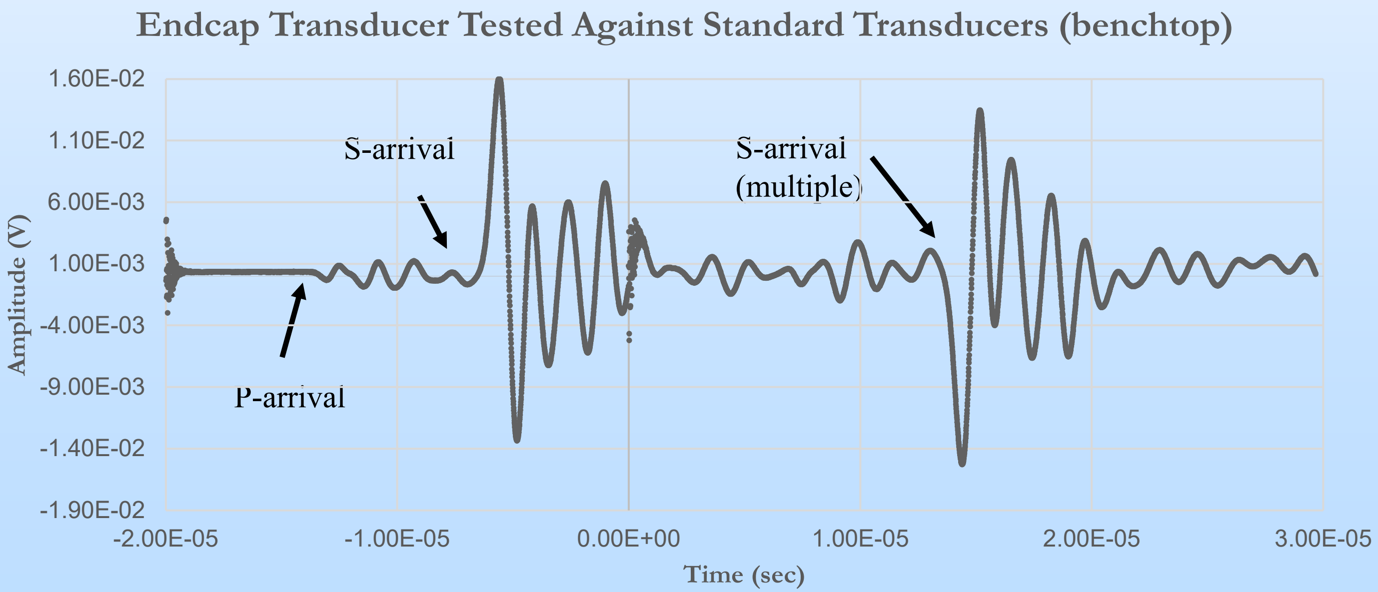
	x-Direction	y-Direction	z-Direction	Porosity
Intrinsic Permeability (hydrate can flow)	226.0 mD	224.0 mD	169.5 mD	29.9 %
Permeability (with hydrate as a solid)	1.56 mD	1.47 mD	1.23 mD	13.4 %

Cryogenic Core

Multiphysics – Joint Acoustic & CT Imaging







Future Work

1. **Direct observation and quantification of hydrate phase change and its effect on flow under production condition by micro-CT**
   - Correlation between properties measurements at different scales and the pore scale observations
2. **Geomechanical stability of reservoir during gas production**
   - Core-scale laboratory production tests with triaxial chamber or high stress effective stress chamber
     - Direct deformation measurements under depressurization
     - Compressibility, strength and stiffness, initial/intrinsic permeability vs. hydrate saturation.
3. **Permeability transition over the boundary between overburden and hydrate reservoir**
   - Comparison of permeability over the transitioning (or boundary) zone at top and bottom of reservoir formations

Achievements

1. **Analysis of cryogenically preserved hydrate-bearing sediment:**
   - **Hydrates were preserved during transition period**
     - Derived hydrate saturation and porosity from high resolution CT images corresponds to pressure core derived values
     - Multiphysics approach to measure acoustic wave velocities at in-situ conditions

2. **Pressure core analysis**
   - **Effective stress measurements are underway**
     - Continue experiments on next pressure core sample