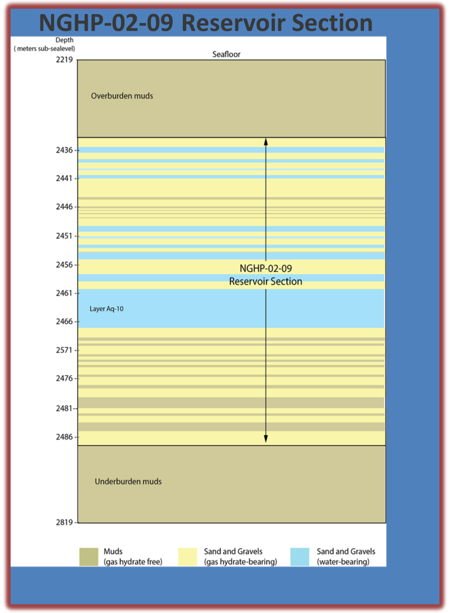
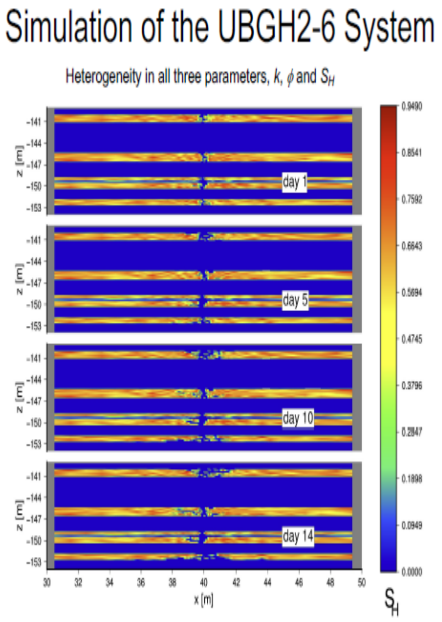
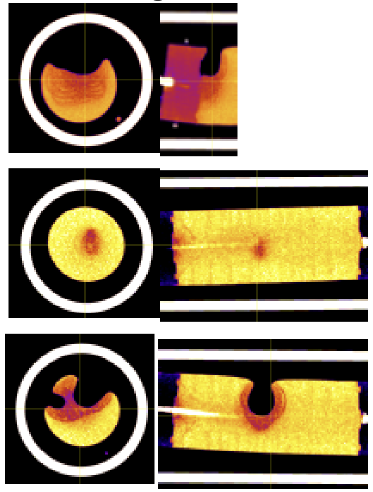
DOE National Labs - Gas Hydrate Field Work Proposals

Methane Hydrate Advisory Committee Meeting

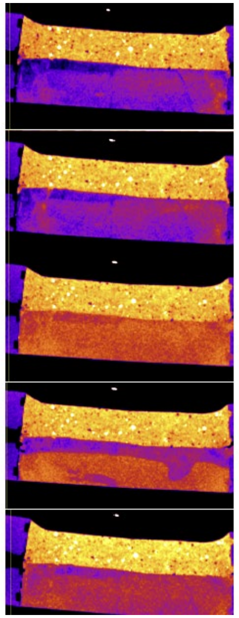




Geomechanical Changes from Effective Stress during dissociation



Layered Hydrate Bearing System



Pre-hydrate

Hydrate-bearing

Hydrate-bearing water saturated

Hydrate-bearing with gas flow

Post Dissociation

National Lab FWPs

- **Two types of FWPs**
  - Stand alone FWPs (NL only efforts)
    - focus on addressing specific program needs (lab and modeling studies primarily)
    - Offer flexibility through annual decision on work scope
  - Support FWPs (NL efforts as part of larger FOA selected project)
    - Contribute specific activities in support of a bigger project
    - Leveraging of complimentary activities under stand alone FWPs

- **Six active (or recently active FWPs) with 3 NLs**
  - Stand Alone
    - LBNL Lab Studies
    - LBNL Numerical Studies
    - LBNL KIGAM Collaboration (ended in May 2018, final report completed in early 2019)
    - PNNL Numerical Studies
  - Support
    - LBNL support of TAMU/KIGAM Cooperative Agreement
    - LLNL support of UCSD-Scripps Cooperative Agreement

- **NETL RIC FWP**

LBNL – Gas Hydrate Lab Studies

ESD12-011 / FP00008137

Formal Title: **Properties of sediments containing methane hydrate, water, and gas subjected to varying stimuli and conditions**

Dates: ESD12-011: FY12 – FY18; FP00008137: FY19 – TBD

Funding: ESD12-011 – $685k; FP0008137 - $145k (to date)

Overall Objective: Measure physical, chemical, mechanical, and hydrologic property changes in hydrate systems subjected to varying stimuli and conditions (injection of non-methane gases, effects of sediment layering, and effects of relevant (thermal, chemical, and capillary pressure) gradients on hydrate behavior.

Key Accomplishments:

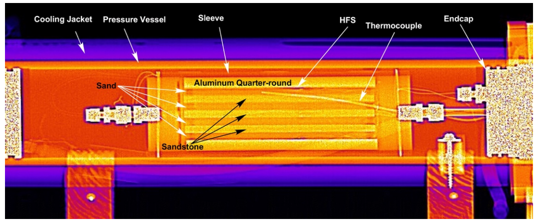
- Investigated flow and geophysical properties of GH bearing sediments undergoing gas exchange
- Developed lab tools & techniques, and performed numerous tests to examine GH behavior in increasingly more realistic environments (controlled thermal/chemical gradients; well analogs; layered systems)

Key Findings:

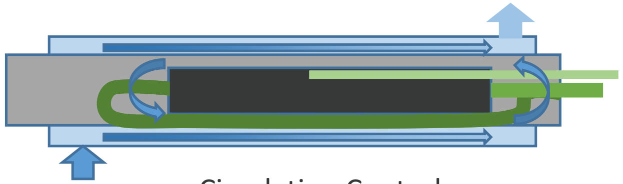
- MH exposed to 77% N2 23% CO2 gas experienced dissociation and phys. prop. changes. A range of stable 3-phase states over temp. (4 - 9 C) at constant pressure was encountered from different MH compositions.
- In salty water, rapid mass transfer relative to rate of dissociation leads to salty water equilibrium conditions, slow mass transfer relative to the melting process leads to fresh water equilibrium conditions.
- Without sand control, geomechanical sample failure is likely under reasonable flow and effective stress. With sand control, samples did not fail for either fast or slow depressurization.
- GH in sand/mud layered systems formed in sand only. Mud layers compacted with effective stress changes.

FY19 Activities:

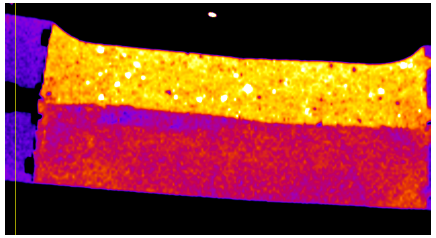
- Laboratory benchmark geomechanical tests for code validation in coordination with code comparison group, for both cementing and pore filling GH



Layered System



Circulation Control



Compacting Mud (top)

LBNL – Gas Hydrate Numerical Studies

ESD12-011 / FP00008137

Formal Title: **Numerical Studies for the Characterization of Recoverable Resources from Methane Hydrate Deposits**

Dates: ESD12-011: FY12 – FY18; FP00008137: FY19 – TBD

Funding: ESD12-010 – $1,250k; FP0008138 - $500k (to date)

Overall Objective: Enhance existing numerical simulators, and perform studies on the characterization and analysis of recoverable resources from hydrate deposits, the evaluation of appropriate marine and arctic hydrate production strategies, and the analysis of the geomechanical behavior of GH-bearing sediments, in addition to providing support for DOE's GH-related activities and collaborative projects.

Key Accomplishments:

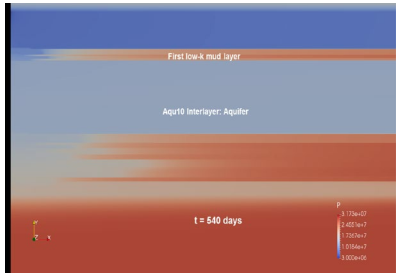
- Developed T+H quantitative predictive capability to describe / simulate production from GH deposits
- Developed coupled geomechanics capabilities & understanding of the geomechanics of GH reservoirs
- Contributed to design / eval. of worldwide GH field tests (PBU-L106, Ignik Sikumi, UBGH2-6, NHGP-02)
- Published or submitted over 10 peer-reviewed papers since 2012 (50+ overall)

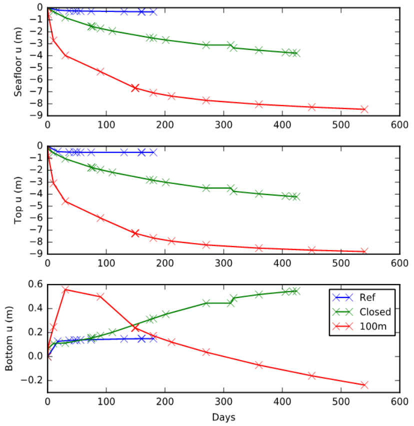
Key Findings:

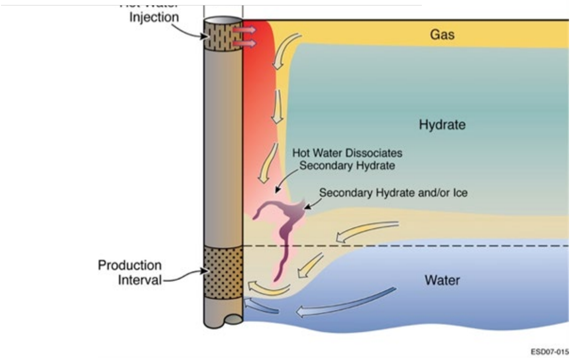
- Careful characterization of reservoir boundaries is essential to assessing production potential.
- Geomechanics is key to realistic simulation of reservoir evolution, beyond assessment of geohazards
- Large & small-scale simulations required to understand GH behavior—subtle thermodynamic behavior and fine structure is important for description large-scale reservoir performance

FY19 Activities:

- Fully parallelize Millstone geomechanics code, and couple it with the parallel T+H
- Provide simulation based design support for a DOE-led field test in the North Slope of Alaska
- Provide support for and participation in 2nd International GH Code Comparison Study
- Evaluation of potential for High-Efficiency Modeling Methods for GH Reservoir Simulation







LBNL - S. Korea (KIGAM) Collaboration

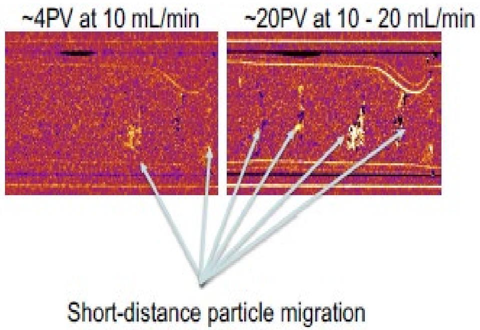
FP0003995

Formal Title: **LBNL-KIGAM Collaboration in the Investigation of the Gas Production Potential of Hydrate Deposits in the Korean East Sea**

Dates: FY16-FY18

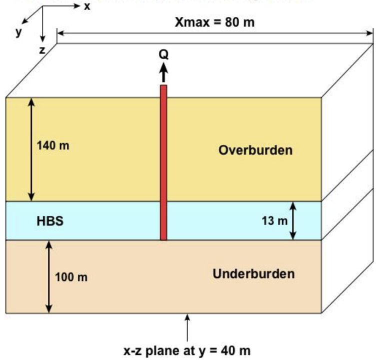
Funding: DOE - $125k; KIGAM - $150k

Overall Objective: Improve understanding of potential production of methane from hydrate deposits in the Ulleung Basin (Korean East Sea) contained in seismic chimneys and in mud-confined layered sand/mud systems through numerical and experimental investigations of the challenging environment present there



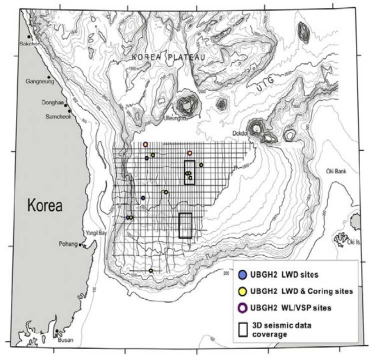
Key Accomplishments:

- Improved capabilities to T+H allowing better simulation of Ulleung Basin-type hydrate deposits.
- Key simulations of Ulleung Basin (UB) GH production (examined fluids flow, heat transfer, and geomechanics.
- Lab techniques to investigate particle transport and mechanical properties of sand/mud layered systems.
- Tests to examine behavior of UB-like GH deposits including particle transport and geomechanical behavior.



Key Findings:

- Under modeled conditions, displacement can be significant (<0.4 m to ~1m) over 14 day production period.
- Max displacements are above and below the production zone & require engineering to address.
- Under extreme flow conditions while mechanically stable, some particle migration occurs. In these tests migration was measurable, but not geomechanically significant.
- SAND MUST BE CONTROLLED or failure may be catastrophic.



LBNL - TAMU Project Support

FP00003997 (Conducted as part of Cooperative Agreement DE-FE0028973 with TAMU / KIGAM)

Formal Title: Advanced Simulation and Experiments of Strongly Coupled Geomechanics and Flow for Gas Hydrate Deposits: Validation and Field Application

Conducted as part of: Coop. Agr. DE-FE0028973 with TAMU / KIGAM

Dates: FY16 – FY19

Lab Funding: $225k; (DOE funding to TAMU CA - $506k)

Overall Objective (of labs activities): Perform laboratory tests appropriate to the UBGH2-6 borehole to examine geomechanical processes such as sanding, capillarity, and formation of secondary hydrate and instruct students in the use of simulation codes to analyze the geomechanical effect of hydrate dissociating in systems similar to UBGH-2 or PBU L106.

Key Accomplishments:

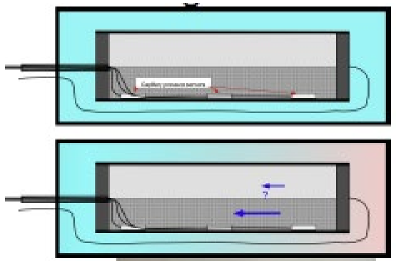
- Investigated dissociation of GH in sands under conditions expected for Ulleung Basin production
- Investigated importance of sand control under effective stress change and flow.
- Trained TAMU students in the use of TOUGH+Hydrate

Key Findings:

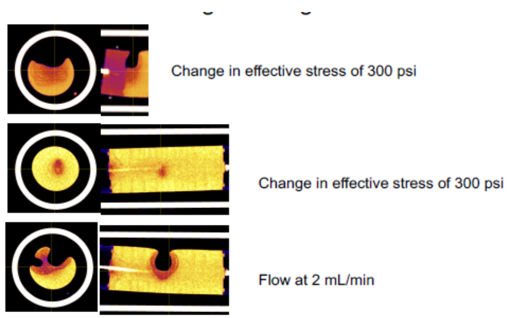
- Sand flow under water flow conditions may lead to catastrophic failure
- Effect of capillary forces may mitigate this (under current investigation)
- Simulated results show possible subsidence at the seafloor of < 0.2 m.

FY19 Activities:

- Evaluate geomechanical changes resulting from secondary GH and capillary pressure changes
    - Design and construct capillary pressure sensors at a range of gas entry pressures
    - Assess the geomechanical and capillary behavior of moving and accumulating hydrate
- Continue support of TAMU students in their simulation-based analysis of system behavior at the Ignik-Sikumi and Ulleung Hydrate Deposits



Capillary Pressure Sensor for use in geomechanical evaluation



CT of geomechanical changes with change in effective stress

PNLL - Gas Hydrate Studies

FWP 65213/72688

NATIONAL ENERGY TECHNOLOGY LABORATORY

Formal Title: Coupled Hydrologic, Thermodynamic, and Geomechanical Processes of Natural Gas Hydrate Production

Dates: FWP 65213: FY13 – FY18; FWP 72688: FY19 – TBD

Funding: FWP 65213 – $370k; FWP 72688 - $100k (to date)

Overall Objective: Investigate numerically, the coupled processes for production of hydrates from geologic including both conventional (depressurization, thermal stimulation, and inhibitor injection), and unconventional (nitrogen / air injection, and former swapping) hydrate production approaches.

Key Accomplishments:

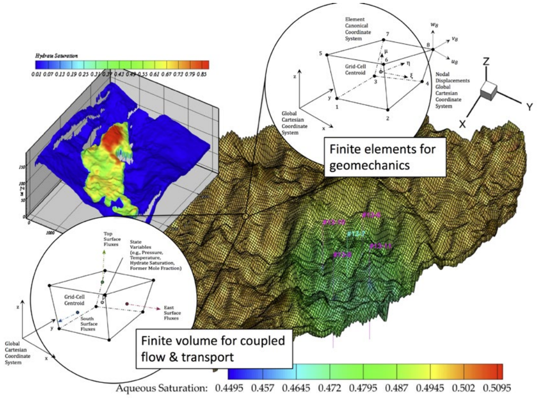
- Developing STOMP-HYDT-KE with capabilities for ternary GH, full kinetics, coupled geomech. & geochem. for conventional & unconventional production technologies.
- Successful modeling against the Ignik Sikumi field trial, including the compositional exchange of guest molecules and non-uniform recovery of nitrogen and oxygen.
- Establishing 2nd International Gas Hydrate Code Comparison Study (21 institutions)

Key Findings:

- Kinetic models for GH dissociation, formation, and guest molecule exchange are essential for simulating unconventional reservoir production technologies.
- Production of GH reservoirs via pure CO2 injection is not viable (secondary hydrates).
- GH dissociation via N2 injection shown as possible experimentally and via STOMP-HYDT-KE.
- Injecting gas mixtures into GH reservoirs provides a control mechanism via varying concentrations.

FY 19 Activities:

- Completed final reporting of activities under FWP 65213 in early 2019
- Wrap up of IGHCCS-2 benchmark problems and shift to full reservoir challenge problems
- Parallelization of STOMP-HYDT-KE for more efficient simulation



IGHCCS2
2ND INTERNATIONAL GAS HYDRATE CODE COMPARISON STUDY

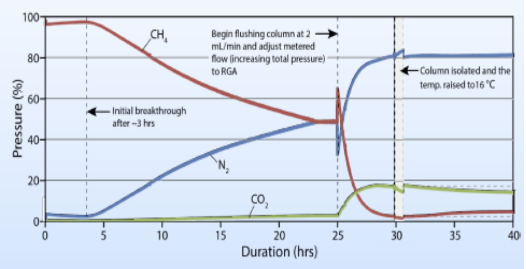


Figure 3. Partial pressure values of CO2, N2, and CH4 obtained from continuous gas sampling of CH4 hydrate bearing porous sand column during a titration of 90% N2 and 10% CO2 gas mixture.

NETL RIC FWP

BLUF

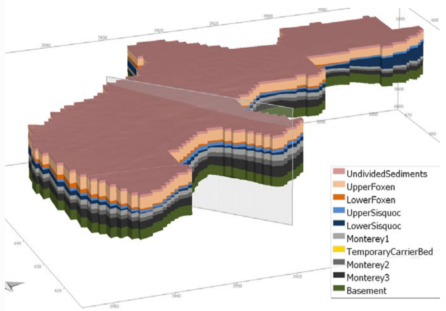
- **Overarching goal of FWP**
  - To promote understanding of intricate **hydro-thermo-mechanical coupled processes** in hydrate systems,
  - To provide key parameters for reservoir simulators of production potential prediction, and
  - To advance the **fundamental sciences filling knowledge gaps** for safe and economic exploitation of hydrate deposits.
- **Accelerating Program Success by providing:**
  - **Numerical simulation assistance**
    - Enable the accurate prediction of reservoir performance based on realistic reservoir models with key reservoir properties derived from hydrate-relevant materials
  - **Enhancing fundamental understanding**
    - Provide basic knowledge on hydrate behavior and develop comprehensive database of hydrological and geomechanical properties
  - **Field production test support**
    - Provide analytical tools for field retrieved pressure cores or conventionalized sediments
    - Production test design support
  - **System analysis of gas resources and supply/demand**
  - **Promoting interagency and international collaboration: Code comparisons, Core analysis collaboration**

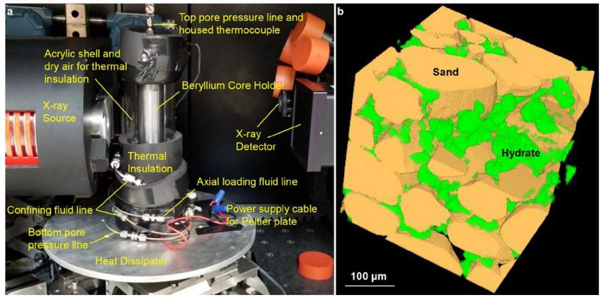
NETL RIC FWP

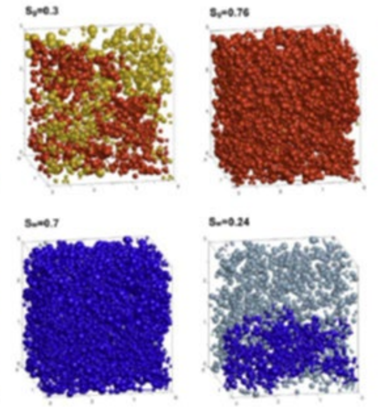
NATIONAL ENERGY TECHNOLOGY LABORATORY

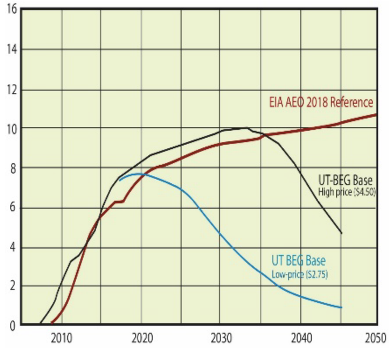
Major Tasks

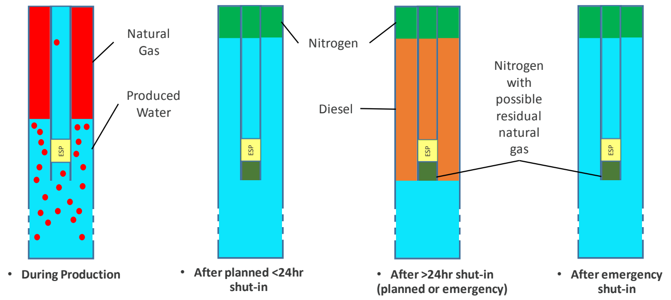
- **Numerical Simulation Support:**
  - Gas Production Prediction
  - Solid Production Simulation
  - Basin and Petroleum System Modeling
  - Laboratory test validation
- **THCM Code Development:**
  - Fully Coupled Open Source THCM hydrate system modeler
- **Laboratory Study for Basic Science:**
  - Hydrological/Geomechanical Property
  - Pore-Scale observations and Modeling
  - Fundamental Understanding of HBS
- **Pressure Core Analysis Tool Development:**
- **Field Production Test Support:**
  - Shut In Procedure
  - Well Completion Method
- **Economic analysis of gas resources and supply/demand**
- **Promoting interagency and international collaboration:**
  - Code comparisons,
  - Core Analysis Working Group











Numerical Simulations Supports

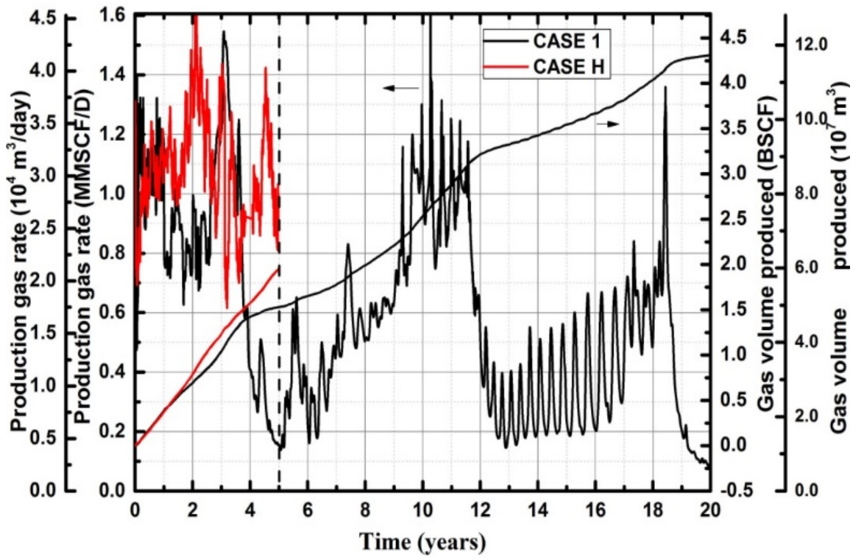
- **Importance**
  - Maintain and develop **numerical modeling capability** to support planning, executing, and analysis of **international and domestic field production tests and long-term prediction of reservoir performance and environmental impacts**.
- **FY18-19 Scope**
  - Numerical modeling supports for **Long-term production tests** in permafrost of Alaska North Slope and the marine gas hydrate deposits, including the Gulf of Mexico and the offshore of India.
  - **Collaboration support** between NETL and JOGMEC (Japan) on development comprehensive reservoir models for Kuparuk 7-11-12 Site on the Alaska North Slope.
  - **Core scale simulations** to complement laboratory studies on functional forms of relative permeability functions governing multiphase flow
  - Development of the **Non-empirical relative permeability model** accounting for the effects of capillary pressure to predict multiphase flow in hydrate-bearing sediments.
  - Application of **Machine Learning** Technology to estimate Key Parameters (e.g., Hydrate Saturation) using limited well log data
  - **3D Basin and petroleum system model** of Terrebonne mini-basin (Gulf of Mexico) and East Coast Basin, New Zealand to aid the understanding of gas hydrate reservoirs and their sensitivity to changing geologic conditions

Reservoir Simulations Support

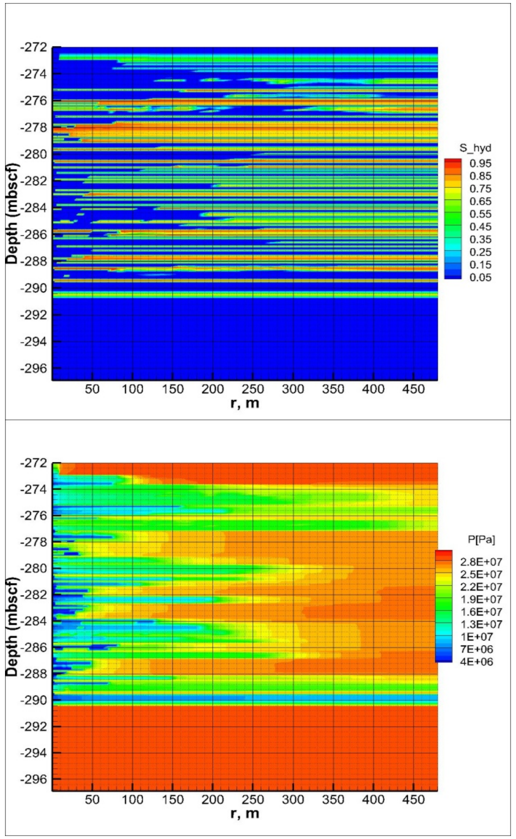
NGHP-02 Site 16

- Development and application of the **interbedded marine reservoir model** for NGHP-03 gas production test
- Mechanism of hydrate decomposition dictated by the **interbedded nature of the reservoir**
- Substantial complexity with presence of vertical and horizontal dissociation interfacies

Site 16 resistivity log image, vertical discretization for CASE 1 homogeneous reservoir properties, Vertical discretization for CASE H with heterogeneous pore fill saturation



Cumulative production gas volumes (red line) and gas rates (black lines) for 5 and 20 years for CASES 1 and 2, respectively.

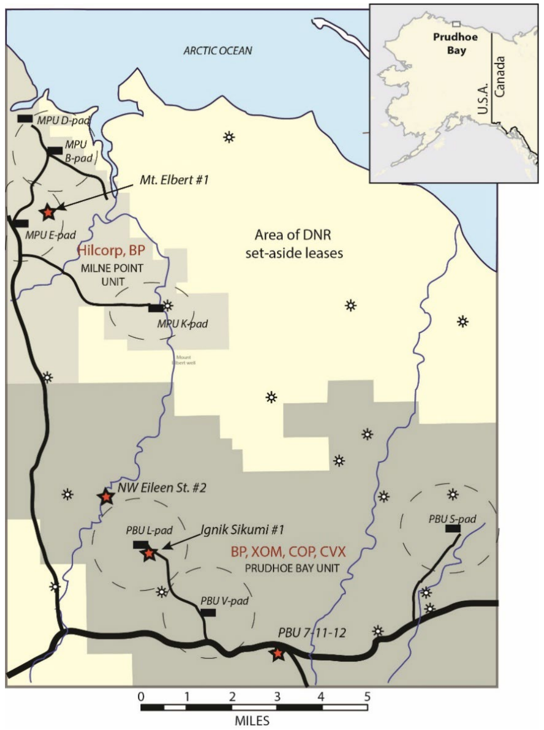


Hydrate saturation and pressure after 5 year for Case H

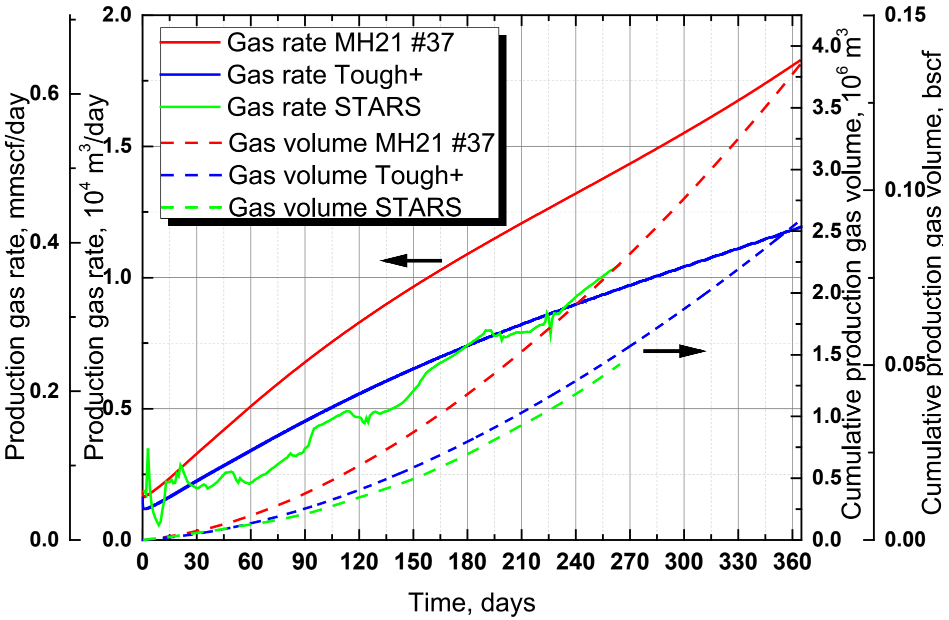
Reservoir Simulations Support

Alaska Long-term Production Test Modeling

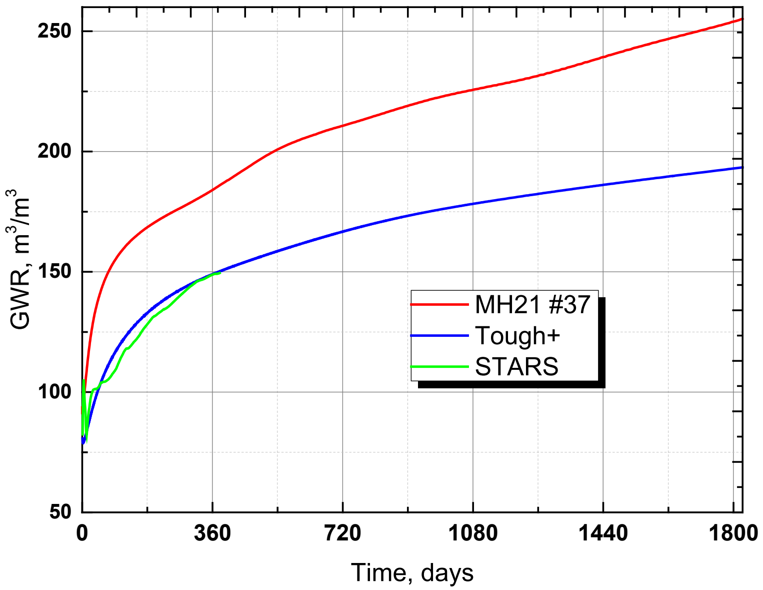
- Development and application of the **permafrost reservoir models** for gas production potential at Prudhoe Bay Unit, Kuparuk Site 7-11-12 to support the field test planning and execution.
- Incorporating similar **thermodynamic, thermal, hydrological models and approaches** into TOUGH+, CMG STARS, and MH21 simulators based on consensus between NETL and JOGMEC teams.



Location of the Kuparuk 7-11-12 Site



Gas rates and cumulative gas volumes produced over 1 year of depressurization



Gas-to-Water Ratio difference resulting in productions, requiring further investigation on water mobility treatment

Basin and Petroleum System Modeling

Terrebonne Basin, GOM

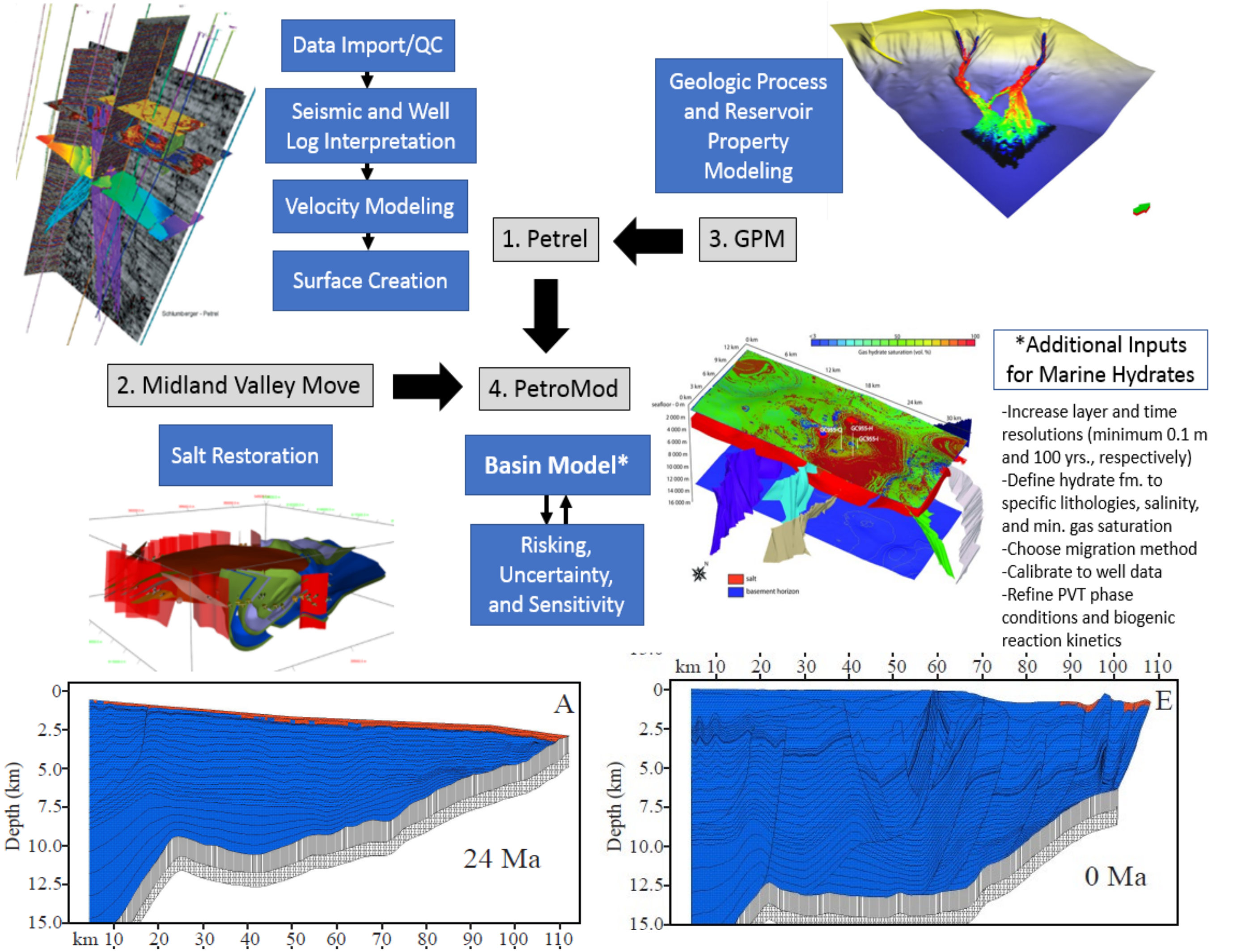
- An integrated workflow developed for modeling gas hydrates that begins at basic data import and quality control and ends at a calibrated basin model.
- Interpreting geologic horizons from seismic and well log and mapping into 2D model,
- Examining gas hydrate stability zone and gas saturations through time on a 3-D test case and sensitivity analysis with lithology and boundary conditions

East Coast Basin, New Zealand

- successfully modeled the qualitative impact of tectonic uplift on gas hydrate dissociation in the basin.

Alaska North Slope

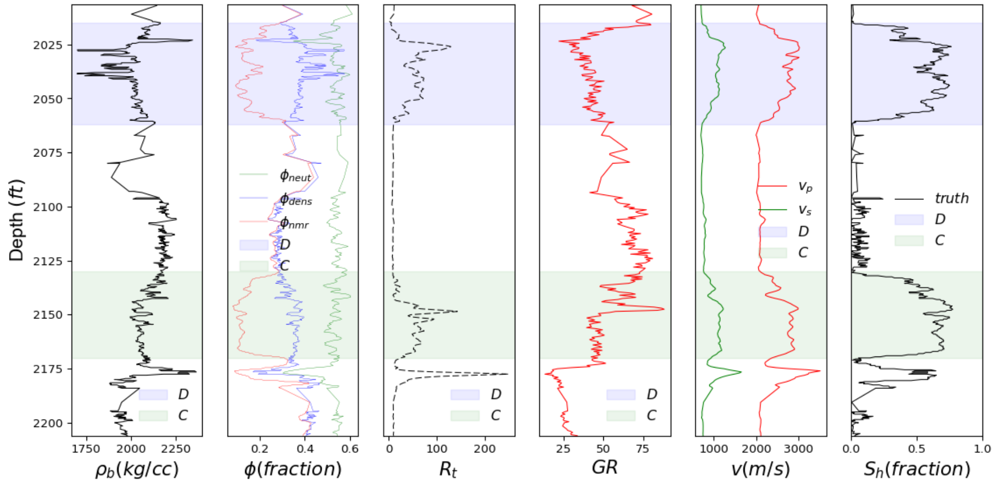
- Developing integrated and cohesive data platform of gas hydrate system for predictive regional-scale model of hydrate distribution

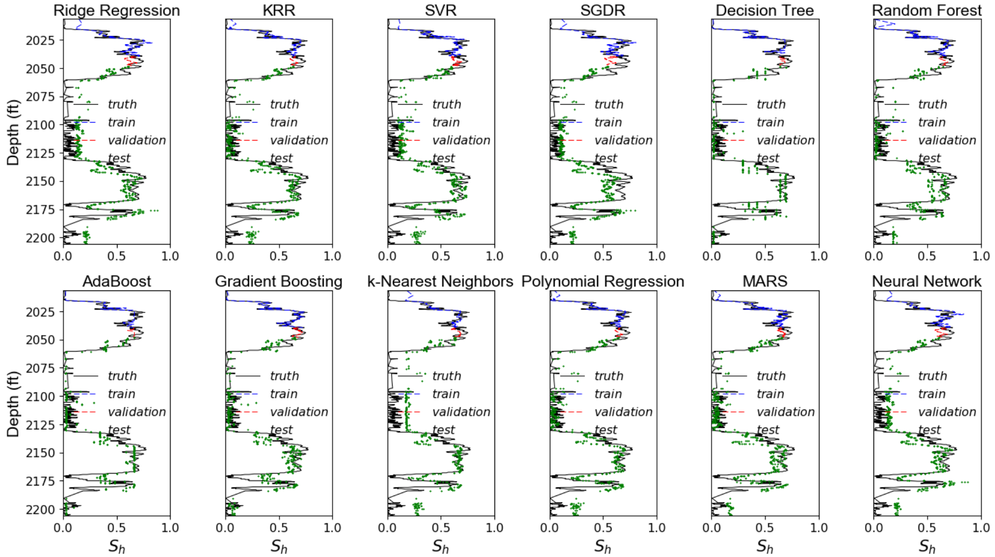


Reservoir Simulation Support

Machine Learning for Log Data Analysis

- **Key parameter estimations from field log data**
- Machine Learning (ML) combining statistics, applied math, and computer science
- 12 supervised learning algorithms to estimate key parameters, e.g., hydrate saturation (S_h)
- Identify underlying functional dependency with some readily available parameters, no mathematical formulations or well-specific calibration (no specialized well logs, e.g. NMR-porosity)
- Training and validation with 15-60% of data (Mt. Elbert: GR, ϕ_{neut}, ϕ_{den}, ϕ_{nmr}, ρ_b, R_t, v_p) to evaluate the rest of the well as well as blind wells (Ignik Sikumi or Hydrate-01).
- Near 80% accuracy of predicting hydrate saturation with a well log combination (ϕ_{neut}, ρ_b, v_p)





Train with 25% of the Data Length for Prediction of S_h with WLC #8 (ϕ_{neut}, ρ_b, v_p)

Reservoir Simulation Support

Machine Learning for Log Data Analysis

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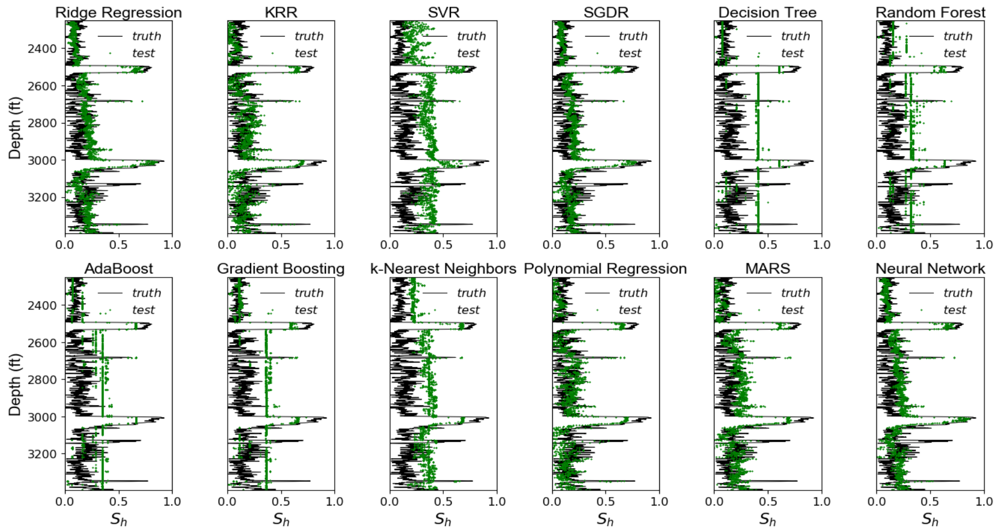
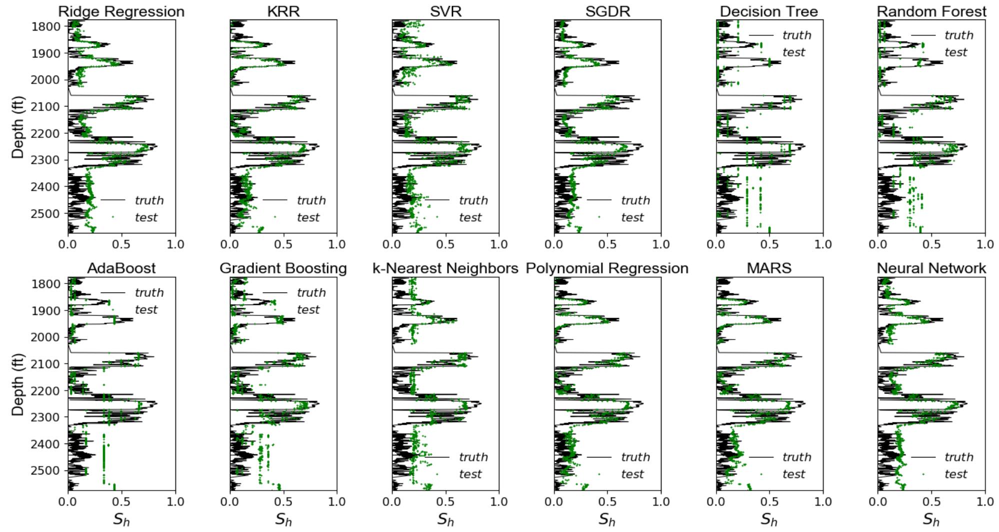


Test of S_h Prediction for a blind well #1 with WLC #8 (ϕ_{neut}, ρ_b, v_p)



Test of S_h Prediction for a blind well #2 with WLC #8 (ϕ_{neut}, ρ_b, v_p)

Thermal-Hydro-Chemo-Mechanical Simulator

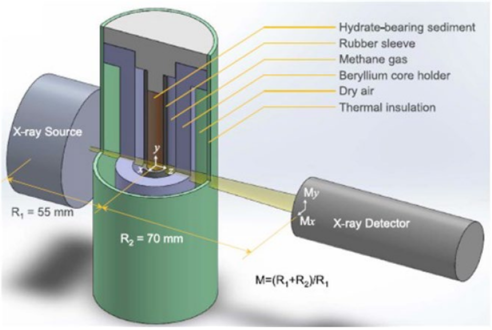
- **Importance**
  - **Stress induced impacts on flow and formation integrity** is critical on high quality prediction of production potential and environmental risk associated with changes in structural integrity during hydrate decomposition in hydrate-bearing sediment
  - **Fully coupled flow-geomechanical formulations** (flow, formation deformation, solid migration) under natural conditions and all possible gas production scenarios (e.g. depressurization, thermal stimulation, brine injection, CO_2/N_2 injection etc.)
- **FY18-19 Scope**
  - The **working version of the NETL-owned THCM simulator** with capabilities for various predictions of hydrate reservoir responses including gas production, water production, sediment deformation, sand migration
  - Implementation of **advanced nonlinear geomechanical constitutive model**
  - Extended numerical modeling to **assess risk of sand production** during gas production
  - Participating **2nd International Code Comparison study (ICCS2)**

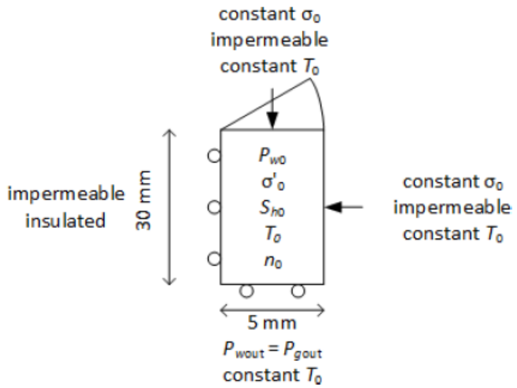
Thermal-Hydro-Chemo-Mechanical Simulator

M3HMS

- **Objective**
  - Development of a **Thermal-Hydro-Chemo-Mechanical (THCM) fully coupled simulator (M3HMS)** for methane hydrate reservoir modeling that can predict nonisothermal flow and geomechanical deformation.
- **Approach**
  - Implemented with the latest **split-stress coupling technique, non-linear elastic constitutive mechanical model, time dependent boundary condition, pore pressure projection algorithm, mesh generator, stress redistribution terms, intrinsic permeability reduction,** for realistic simulations for gas production from hydrate reservoir.
  - Benchmark Problems from the **2nd International Gas Hydrate Code Comparison Study validates performance of** the newly developed simulator.
- **Future work**
  - **Sand migration capability integration** and **parallelization** in progress

- 1D Dissociation, no geomechanics
- 1D vertical consolidation: Terzaghi problem
- 1D radial gas production with geomechanics
- 2D axisymmetric gas production, Nankai Trough
- 2D isotropic consolidation, stress relaxation



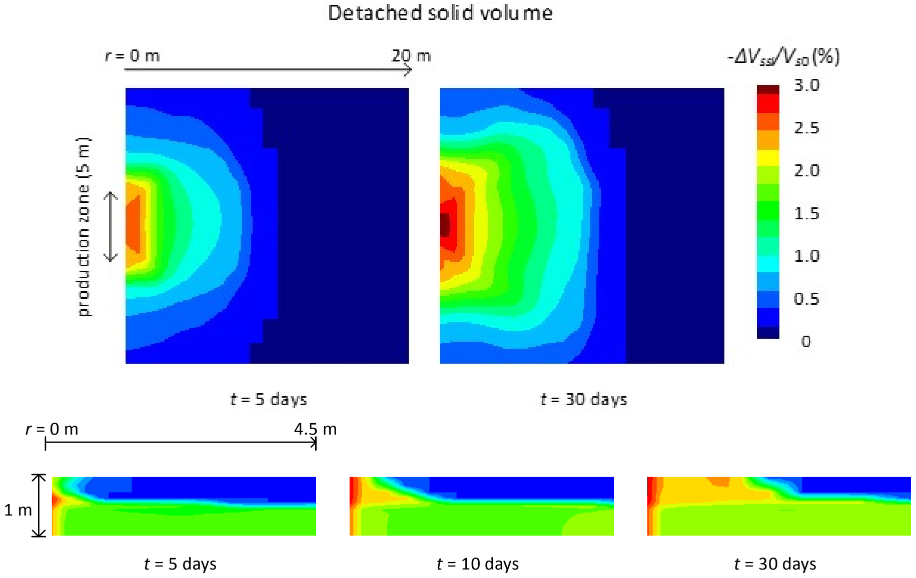


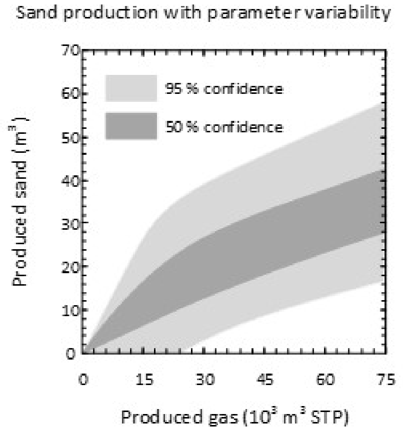
Benchmark problem 5: Isotropic consolidation with hydrate dissociation

Sand Migration Prediction

Sensitivity Study for Conditions to cause sand migration

- **Motivations**
  - Identify what conditions most dominantly cause sand migration, for example, is it pressure drawdown? Depressurization rate? Intrinsic permeability? Sediment stiffness?
- **Accomplishment**
  - Sand migration is likely to continue due to both hydraulic and mechanical changes caused by hydrate dissociation.
  - Sand migration preferentially occurs at the top and bottom end of production zone
  - Higher risk of sand migration with heterogeneity due to greater shearing deformation caused by non-uniform hydrate dissociation.
  - Higher hydrate saturation area has less risk and the most effective to reduce the risk.
  - Shearing deformation and pressure drawdown dominantly affect the produced sand volume.
- **Design Suggestions:**
  - To effectively mitigate the risk of sand migration; **smaller pressure drawdown** will help but lowering the depressurization rate will not.
  - To identify conditions for gas production with lower risk of sand migration; **higher S_h** and **higher permeability**.





Varying conditions	Correlation	Sensitivity indices
Hydrate saturation	-ve	54.2 %
Pressure drawdown	+ve	39.2 %
Effective permeability	-ve	6.0 %
Intrinsic permeability	-ve	0.4 %
S_h dependent sediment stiffness	-ve	0.1 %
Depressurization rate	+ve	0.0 %

Parameter	Description	Sensitivity index
ω1	Effective stress reduction due to grain detachment	0.0 %
ω2	Rate of grain detachment	1.9 %
ω3	Increase in i^{crit0} with hydrate	31.9 %
ω4	Shearing deformation to detachment potential	58.3 %
ω5	Settling/lifting gradient reduction	0.0 %
i^{crit0}	Critical gradient when fully water saturated	7.9 %

Fundamental Property Characterizations

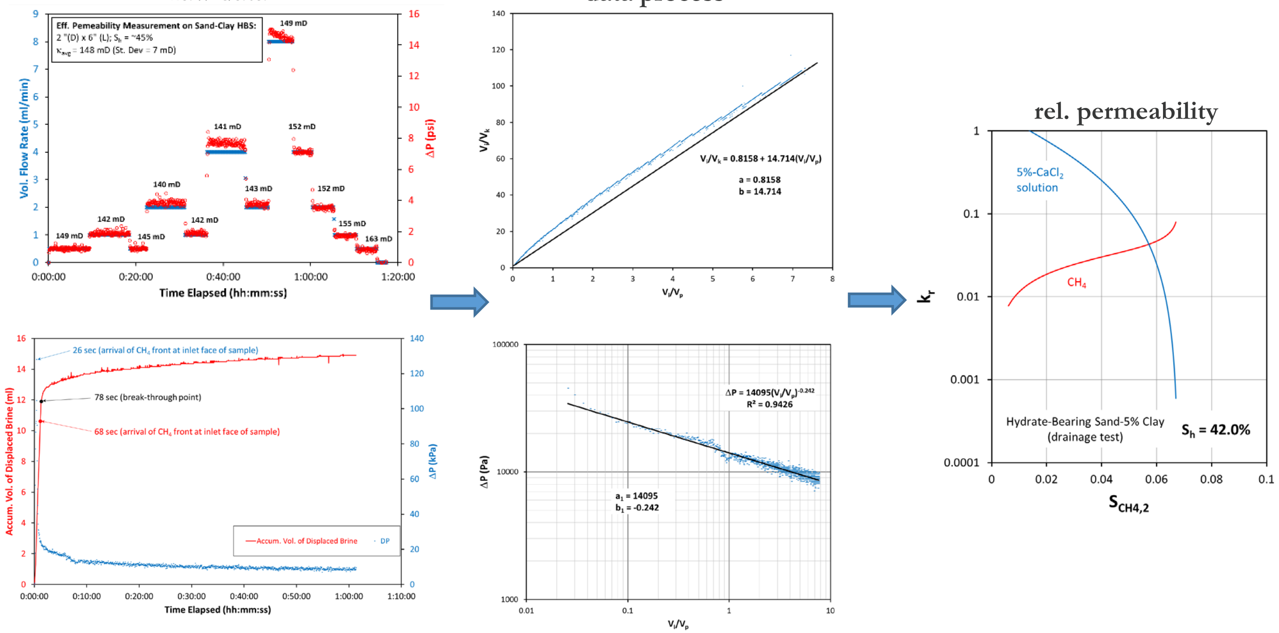
- **Importance**
  - **Hydrate relevant physical properties** (hydrological, thermal, and geomechanical) are critical for accurate predictions of hydrate bearing sediment behavior and flow migrations.
  - **Deficiency in physical properties** including relative permeability and geomechanical strength should be improved for high quality prediction based on numerical reservoir simulations.
- **FY18 Scope**
  - To measure **mechanical and hydrological properties of hydrate-bearing sand** at various effective stresses (grain crushing), hydrate saturations, and clay contents, including permeability, strength, stiffness, dilatancy, and acoustic velocity,
  - To complete **pore scale experimental study of relative permeability** in hydrate-bearing sediments complimented by numerical and analytical models.
  - To visualize **hydrate morphology in sediments** during brine saturation process to understand hydrate formation mechanisms in nature and provide guidance for laboratory specimen preparation and enhanced test data interpretation.
  - To impact of **sand crushing** on permeability under extremely stress condition and **stress-dependent permeability** and **permeability anisotropy**
  - To develop optimal x-ray **CT visualization conditions** for phase separation under 3-phase hydrate stable condition.

Geomechanical and Hydraulic Properties

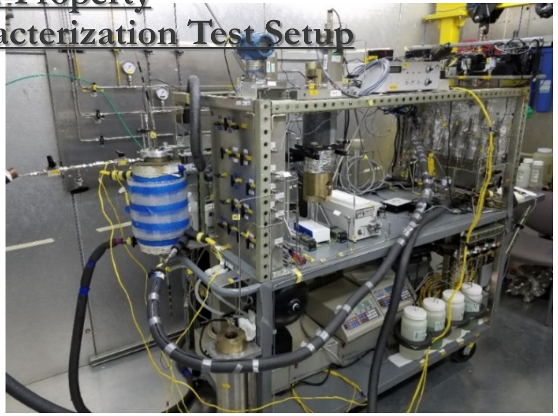
Relative Permeability and Triaxial

- **Approaches**
  - 1 or 2-phase **gas-liquid relative permeability tests** on HBS with different hydrate saturations (0, ~20, ~40%) and **triaxial tests** with clay (5wt%) under stable and dissociation conditions
  - The first set of effective, relative, and intrinsic permeabilities of HBS specimens with clay inclusion
- **Accomplishment**
  - To develop a rel. perm. model that can better represent the characteristics of gas-liquid flow through HBS than the conventional models (B-C, vG, etc.)
  - To support modeling effort by providing input for geomechanical constitutive model development

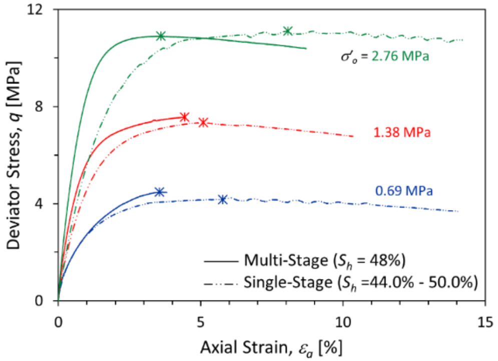
HBS Hydraulic Test Results



Multi-Property Characterization Test Setup



HBS Geomechanical Test Results

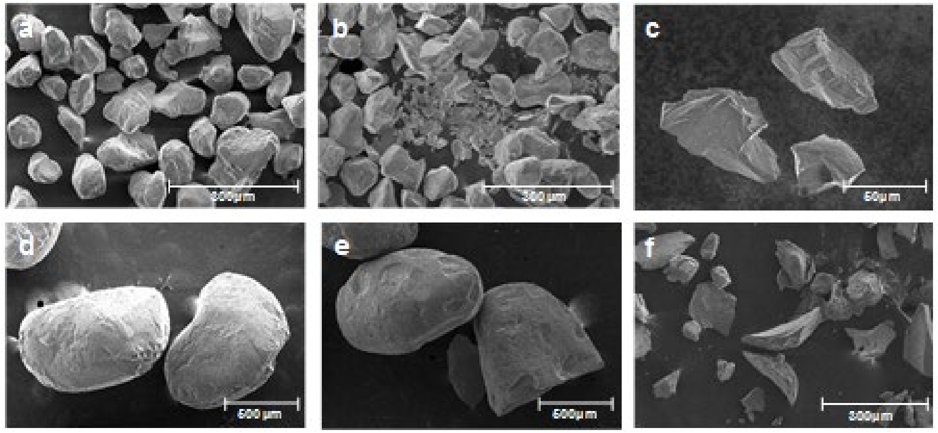


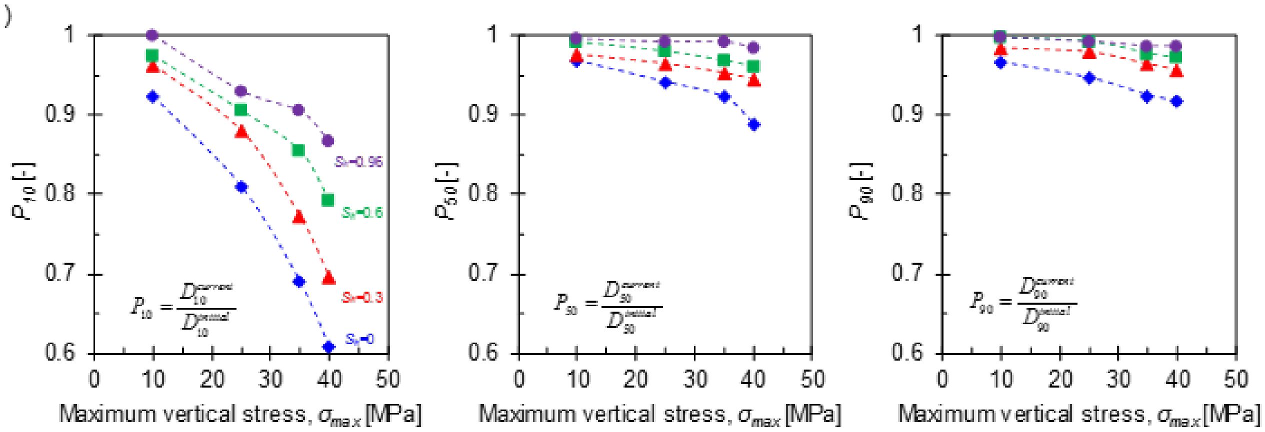
Laboratory Characterization of GOM2 Sediments

Sand crushing in hydrate-bearing sediments

- **Motivations**
  - Sand crushing may occur during depressurization
  - Sand crushing can significantly change sediment's mechanical and hydraulic properties
- **Recent Findings**
  - High stress induced sand crushing may become detrimental to the safety and the economy of gas production from hydrate deposits, as sand crushing
    - causes large volume changes,
    - produces finer particles and exacerbates solids migration and sand production,
    - significantly decreases the pore space and thus the permeability
  - The loss of hydrate crystals execrates sand crushing

SEM images of sands before and after crushing



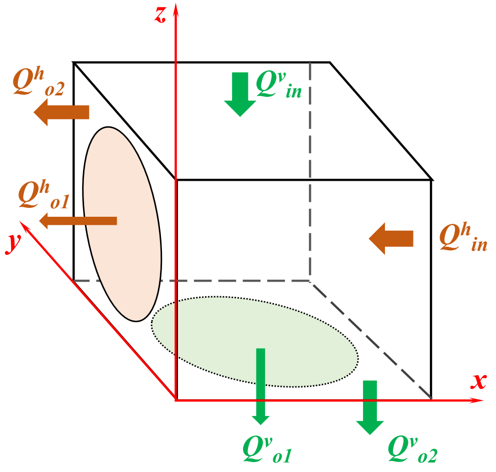


Laboratory Characterization of GOM2 Sediments

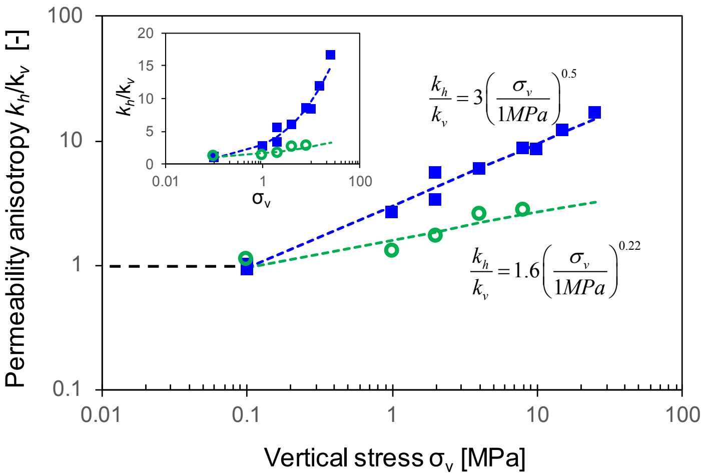
Stress dependent permeability and permeability anisotropy

- **Motivations**
  - Permeability is one of the key parameters governing gas/water flow and thus the gas production efficiency
  - Lab core tests provide vertical permeability while field production is mainly governed by horizontal permeability and affected by vertical permeability
- **Recent Updates**
  - Supporting the NGHP-02 project
  - A customized permeability anisotropy measurement cell (conventionalized core)
  - Stress-dependent vertical and horizontal permeability data
  - Permeability anisotropy is amplified by stress, i.e., vertical permeability decreases faster than horizontal permeability with increase stresses

Permeability anisotropy cell: the double-ring method



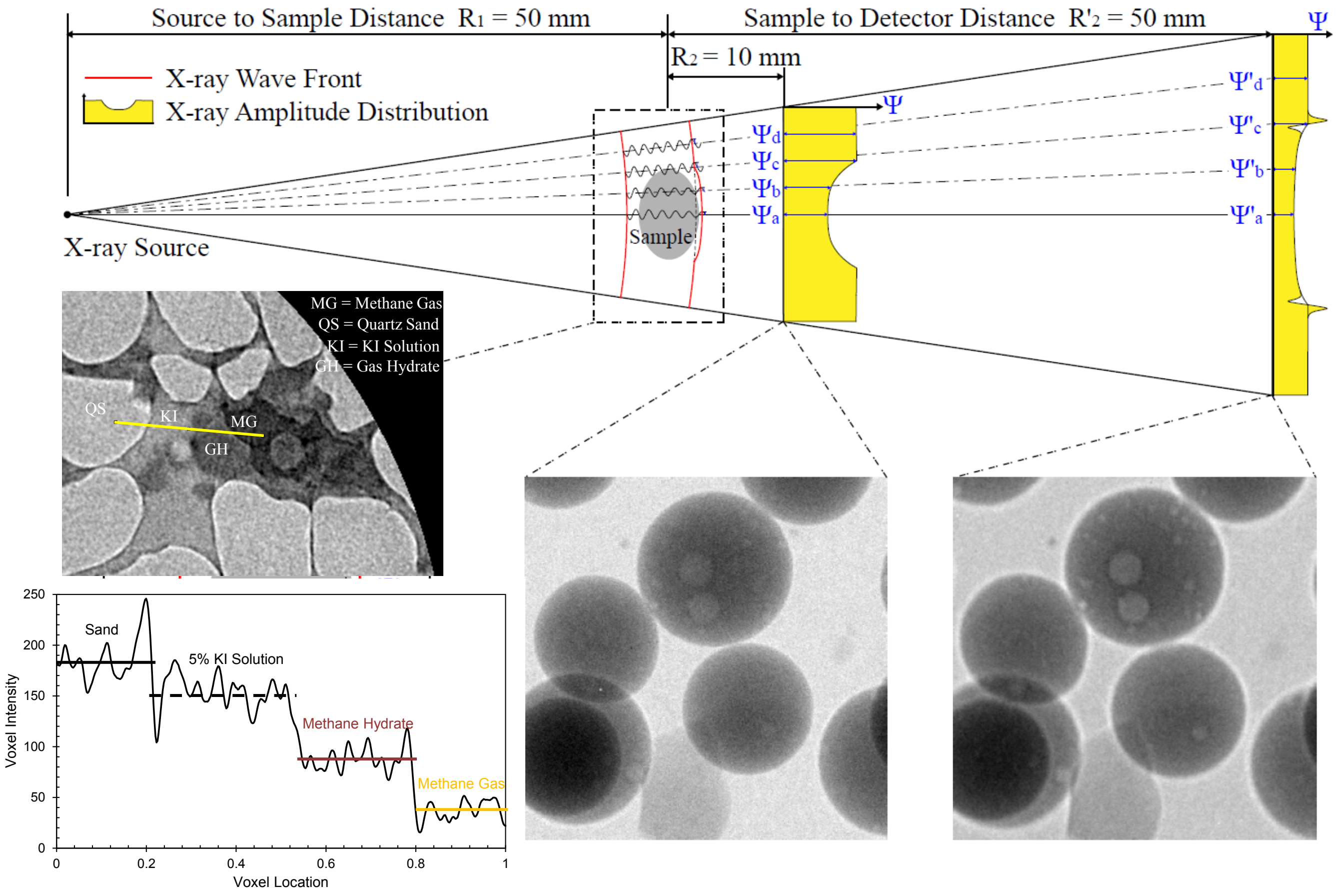
Increasing permeability anisotropy with stress

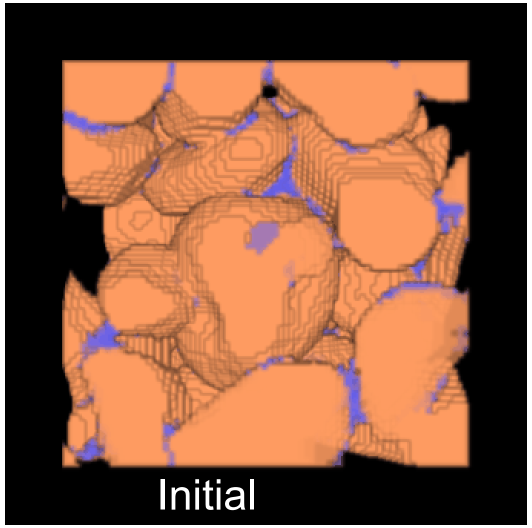


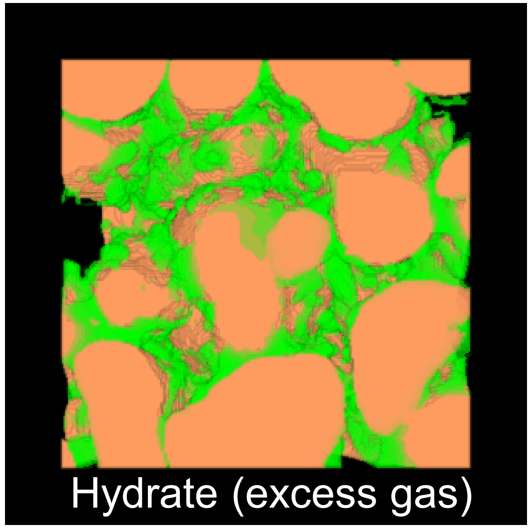
X-ray CT Visualization of HBS

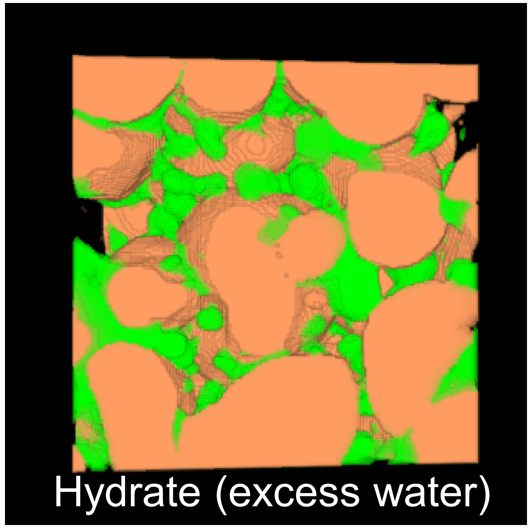
High Resolution Visualization of Methane Hydrate

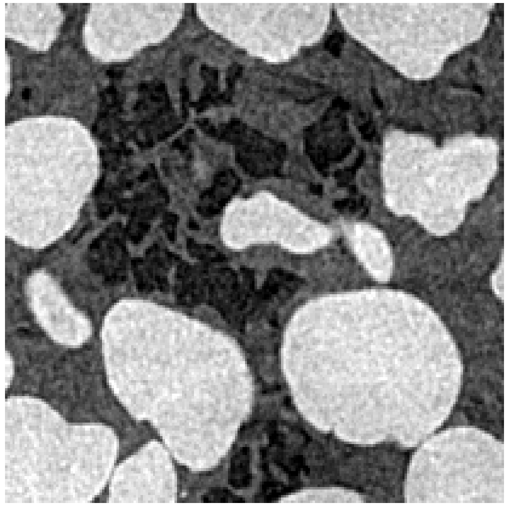
- In-line propagation based phase contract technique
- Enhanced contract with KI salt











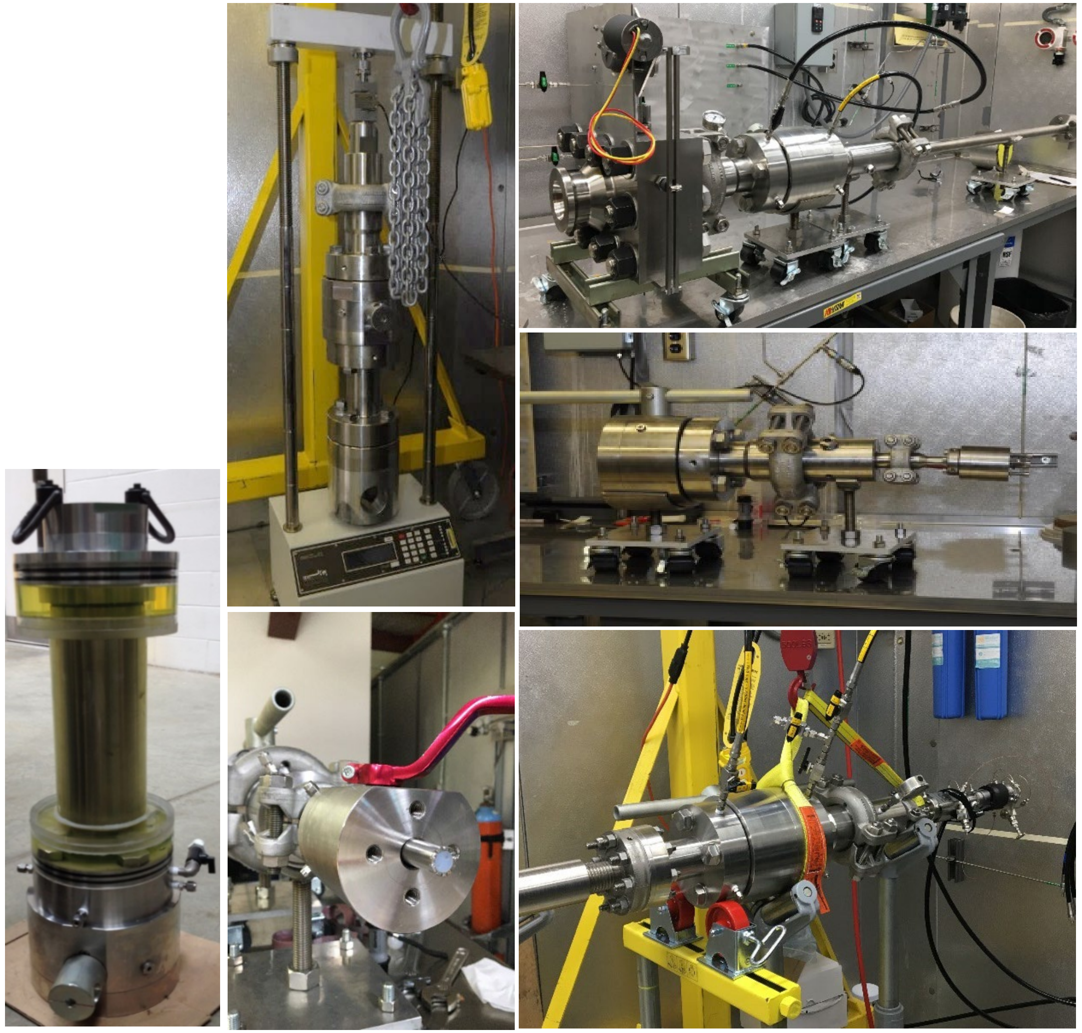
Pressure Core Characterization

- **Importance**
  - Tools to **characterize pressure cores** retrieved from natural condition without any PT disturbance and to visualize hydrate accumulation habits in pore scale are critical for success of hydrate developments
- **FY18 Scope**
  - To conduct compressibility, hydraulic conductivity, strength measurements of synthetized and/or pressure cores with ESC
  - To visualize hydrate pore-habit of natural pressure cores from Gulf of Mexico under various conditions
  - To design and fabricate anisotropic permeability cell (APC)
- **Expected FY18 Accomplishments**
  - **Completed characterization of pressure cores** from the Gulf of Mexico for physical and hydrological properties .
  - **3D maps of hydrate pore** habit in natural sediments and **linkage to larger scale physical properties**
  - Upgrading current PCCT and adding new modules for expanded capabilities,
  - Numerical simulation of fluid and matrix behavior based on digital pore scale structures and estimated physical properties.
  - Beyond: Extend the knowledge learned from pressure cores to guide future research and exploration.

Pressure Core Characterization

*Pressure Core Characterization and X-ray CT visualization Tools(**PCXT**)*

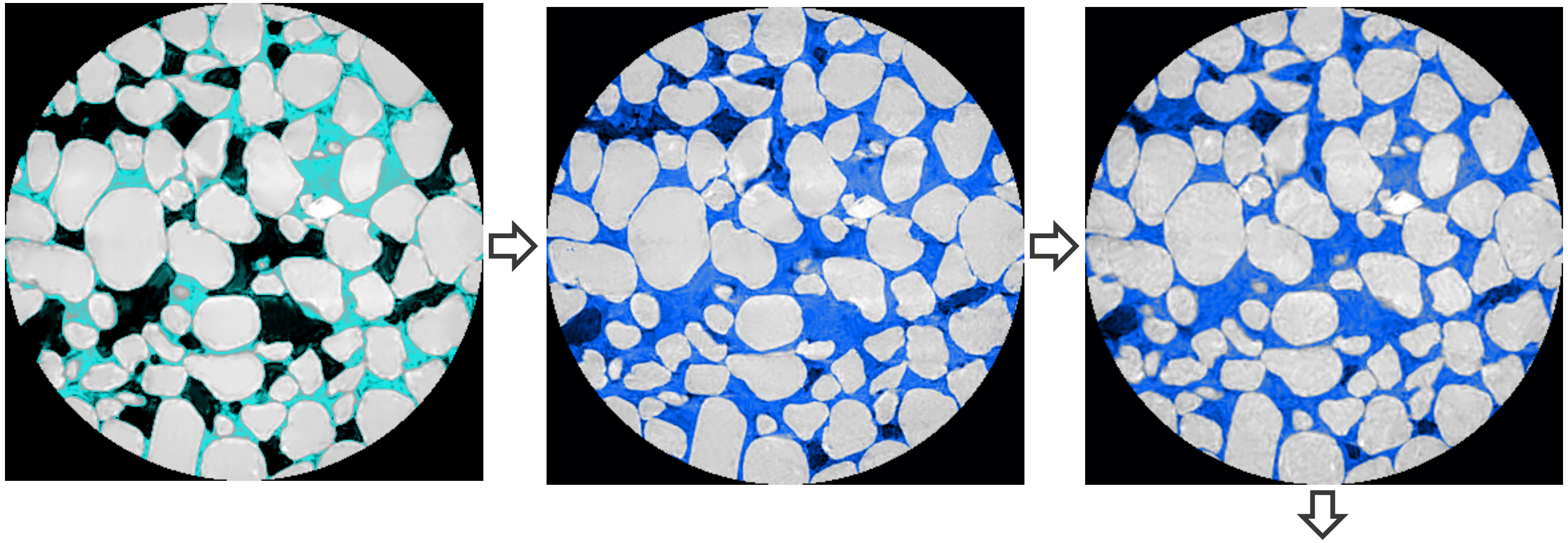
- Completed fabrication of **high-pressure sub-corer, cutter, manipulator, and effective stress chambers** as a part of pressure core characterization tool
    - **First sub-coring capability** for pressure cores for high resolution visualization of pore space
    - Functionality evaluation under progress
- Completed design for **anisotropic permeability measurement cell (APC)**
    - **Multi-directional permeability** measurement capability with pressure-core based sediments
- Completed **transportation of pressure cores from GOM to NETL**
    - No signs of pressure leaks and temperature fluctuations during transit

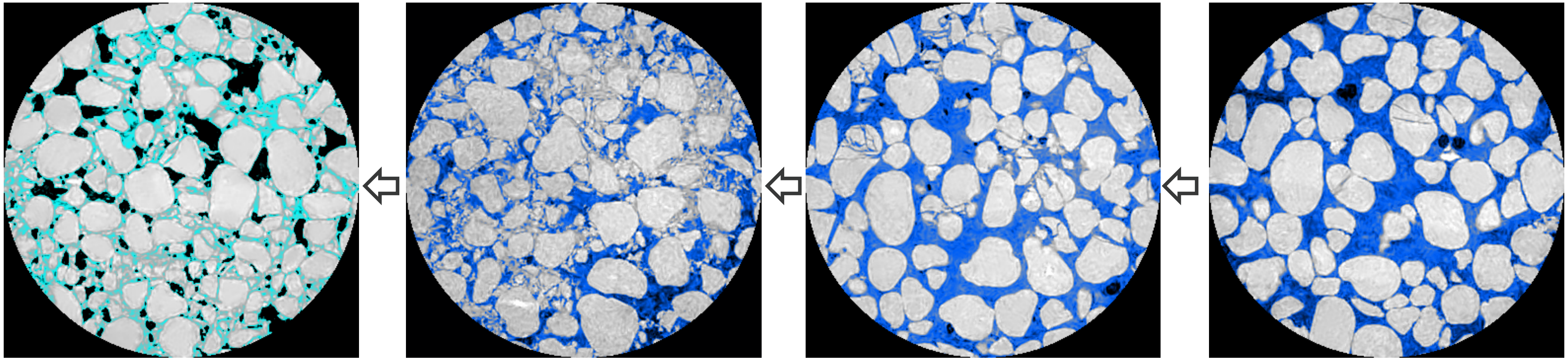


Pressure Core Characterization and X-ray Visualization Tools

Triaxial test on laboratory synthesized HBS

- **Triaxial test on hydrate-bearing sediments**
  - HBS strength ≈ 4 times of HFS
  - HBS strength ↓ as T ↑ (8-12 ˚C)
  - Sand particles crushes → well clogging





Field Test Support

- **Importance**
  - to have a well completion that allows downhole pressures, fluid flow rates, production zone isolation, and solids production to be controlled as tightly as possible.
  - to mitigate and overcome hydrate reformation that can be expected to occur in the borehole during un-intended well shut-ins
- **FY19 Scope**
  - **Well Completion Design and Research**:
    - potential engineering solutions to mitigate such issues
    - the well to be robustly operated for one or more years of proposed experimental operation and observation
    - utilizing the most proven completion technology to prevent solids production
    - requiring as little intervention as possible
    - to minimize the impact on the reservoir and thus on the scientific goals of the test
  - **Well Shut in Research**:
    - allows quick restart of well operations following a shut-in
    - the proposed electric submersible pump (ESP) well completion (co-mingled gas and water production through the same production tubing) requires a revised shut-in procedure to mitigate potential re-formation of hydrates in the wellbore necessary

Systems Engineering and Analysis

- **Importance**
  - Credible forecasts of both gas supply and demand in 2100 time frame.
  - Systems Engineering and Analysis (SEA) efforts provide justification for federal R&D programs that seek to expand US gas supply
- **FY18-19 Scope**
  - A high-level evaluation of the long-term domestic natural gas supply and demand scenarios in the United States; to estimate the likely timeframe at which existing sources can no longer meet supply and to estimate the size of the potential supply shortfall through the remainder of the study period
  - Developing tools to allow us to broadly replicate existing projections to 2050 and to extend them as far as 2100
- **Approach**
  - Development of Excel-based gas production modeling platform to approximately replicate existing forecasts including four prominent shale gas plays
  - Machine learning algorithm to refine the model based on model components for functionality to estimate and forecast drilling activity, well development, and productions in the major plays of interest