Deepwater Methane Hydrate Characterization and Scientific Assessment

DE-FE0023919

P. Flemings, A. Cardona, C. Thomas, and the GOM2 Team

The University of Texas at Austin

Lamont-Doherty Earth Observatory
Oregon State University
The Ohio State University
USGS
University of New Hampshire
University of Washington
Tufts University
BOEM

U.S. Department of Energy
National Energy Technology Laboratory
2021 Carbon Management and Oil and Gas Research Project Review Meeting
October 2022

Presentation Outline

- Introduction
- UT-GOM2-2 Science Expedition, WR 313
- Hydrate Science

Why are we here?

- **5-22% of the world's organic carbon is trapped as gas hydrate**
  - A viable energy source? Response to climate change? Role in Earth's carbon cycle (microbial factory)?

- **Project centerpiece: coring mission to GOM deepwater hydrate reservoir**
  - Determine physical, chemical, and biological properties
  - illuminate origin, dynamic behavior, and response of system to perturbation.
  - First U.S. effort to acquire samples in deepwater hydrate reservoirs.
  - Novel technology to extract rock cores at in situ pressure deep beneath the ocean, bring them to the surface, and study them in laboratories around the world.

GOM2 Objectives

- **To locate, drill, and sample methane hydrate deposits**
- **To store, manipulate, and analyze pressurized hydrates samples**
- **To maximize science through sample distribution, analysis, and collaboration**

UT-GOM2-2
Scientific Expedition
WR 313

- Characterize GOM hydrate-bearing sands

TBD:

- Geochemical profile
- Measurement of in-situ pressure, temperature
- Dissolved methane and gas composition

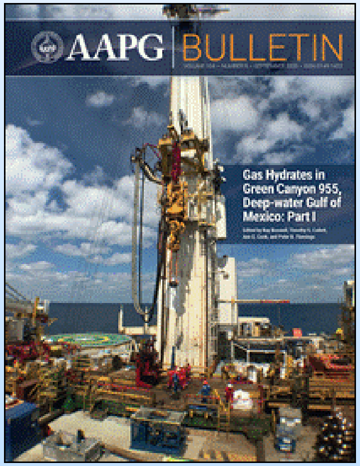
- Modification and Testing of coring equipment
- Core preservation
- Expedition Planning

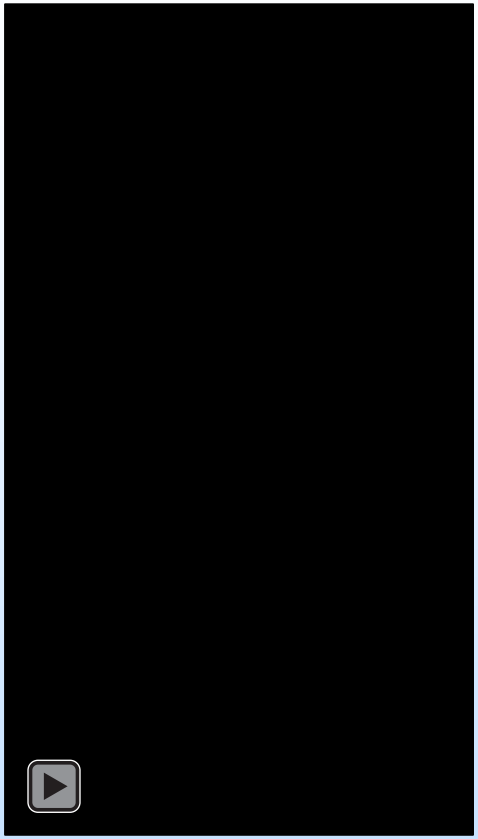
	2020	2021	2022	2023	2024	2025
Phase 4 10/19-09/20		Phase 5 10/20-09/23			Phase 6 10/23-09/25	

Current Status

Accomplishments to Date

- **Successful Field Execution: GOM2-1**
- **Improvements of pressure coring and core analysis equipment**
- **Fundamental contributions in characterization, laboratory analysis, and modeling**
- **Two Dedicated AAPG Volumes summarize GC 955 findings**
- **International research collaboration on pressure core analysis**
- **Ready to execute the GOM2-2 Expedition, WR 313**





UT-GOM2-2

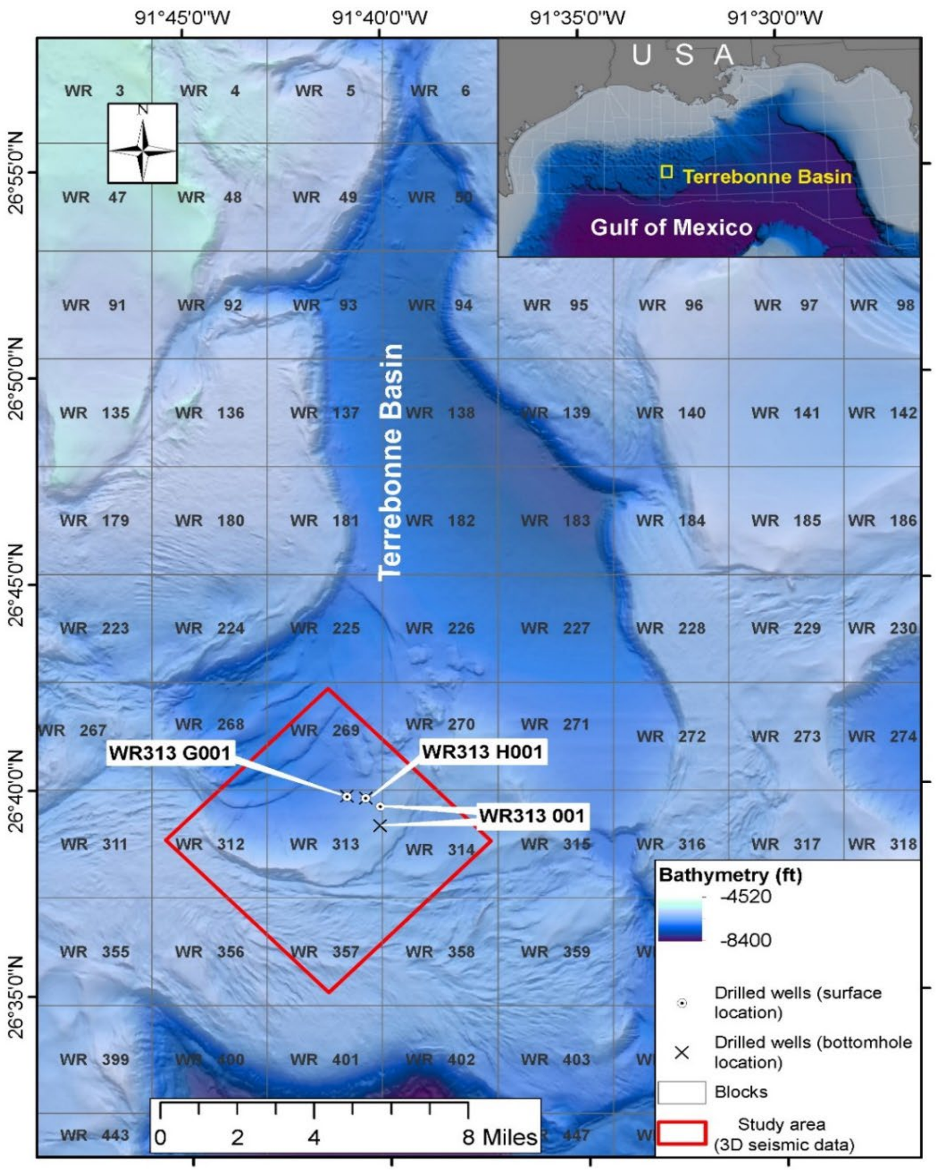
Location: Terrebonne Basin, northern Gulf of Mexico

Sites: WR313 H002 and H003

Dates: May, 2023

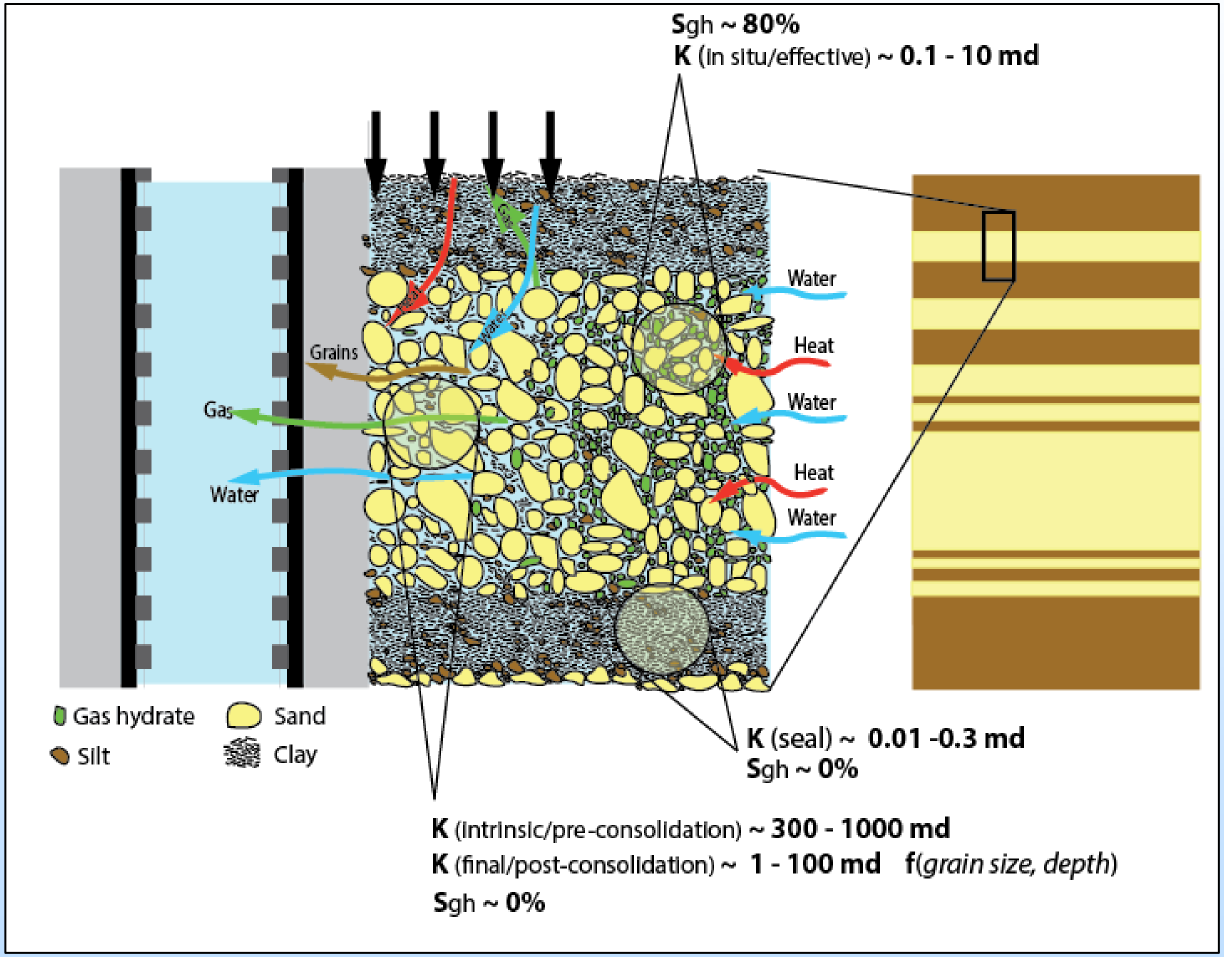
Vessel: Helix *Q-4000*

Duration: Max 34.5 days off-shore, 14 day post-cruise dockside core analysis



Science Objective 1: . Understand Reservoir System

1



Modified from Boswell & Collet, 2016

Steps:

- **Obtain pressure core**
- **Characterize:**

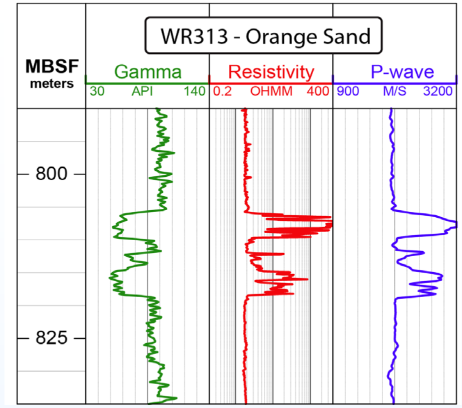
hydrate concentration, gas composition, age, sediment texture, pore water chemistry

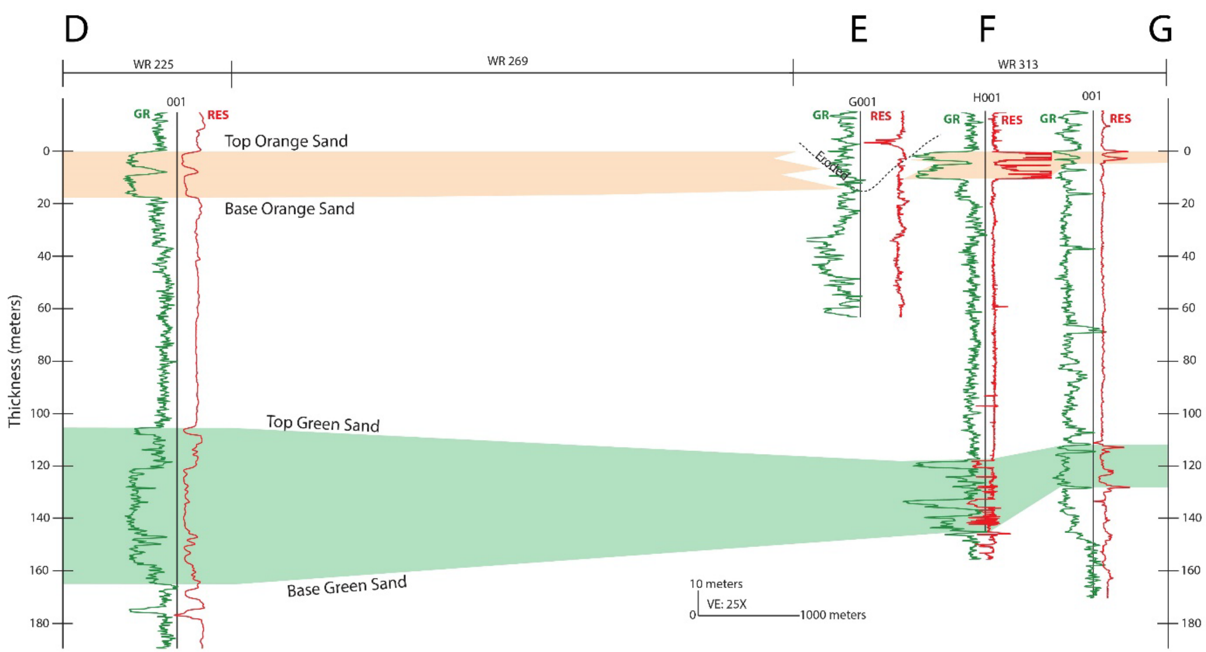
- **Material behavior**

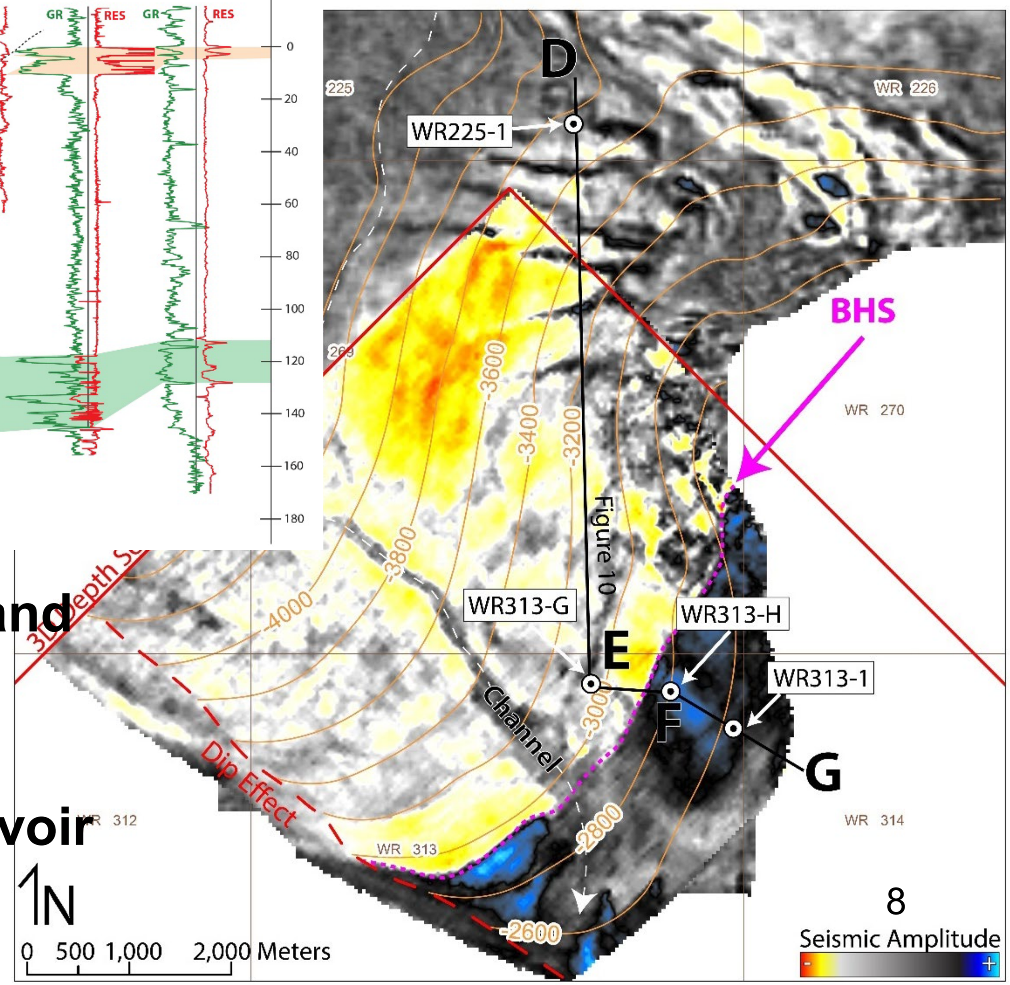
permeability, compression, capillary behavior, strength

- **Elucidate reservoir production behavior** to inform reservoir simulation

The Orange Sand





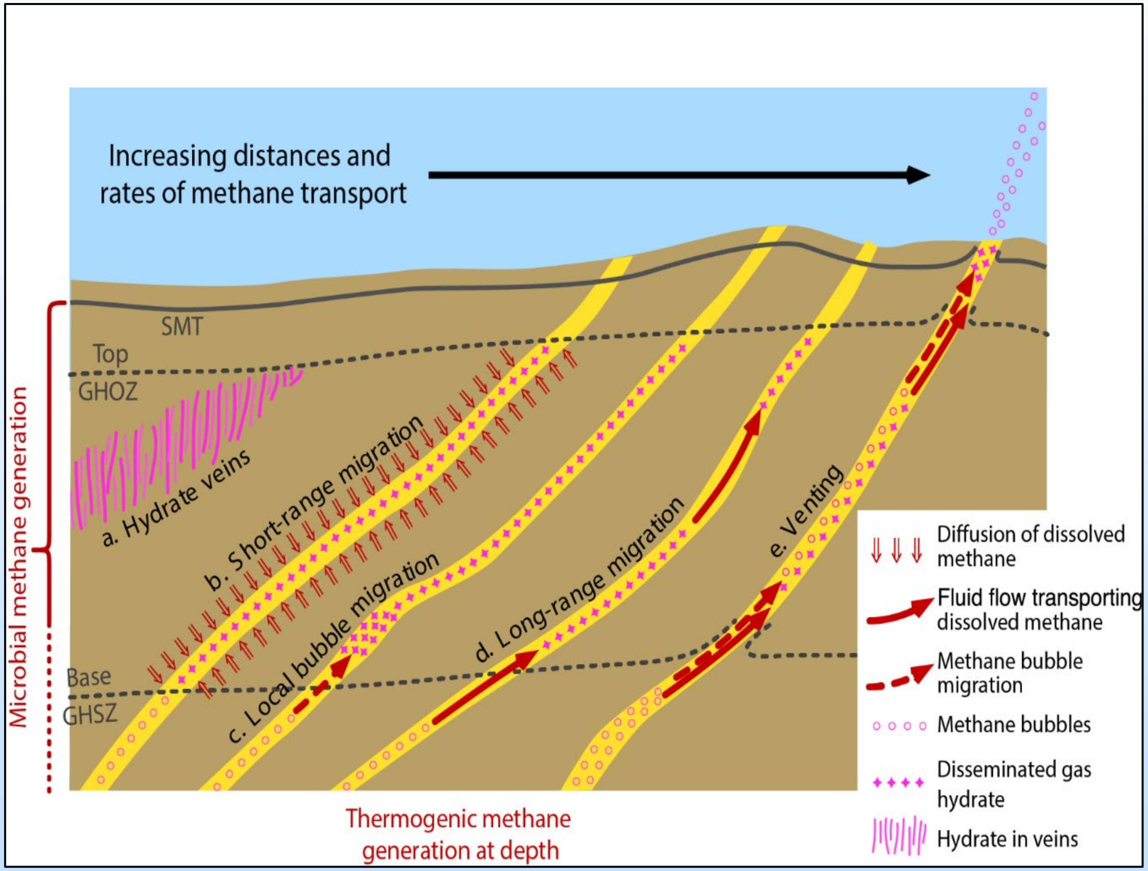


Orange Sand: Regional apron sand that extends across the basin.

Medium-grained extensive reservoir

Science Objective 2: . Understand Basin System

Understanding the Basin System



Malinverno & Goldberg, 2015

Acquire Depth Profile:

- **Collect** cores, gas, and pore water samples, pressure and temperature with depth
- **Characterize** dissolved methane/hydrate concentration, gas molecular composition (microbial source), pore water geochemistry and sedimentology, variation in organic carbon with depth, age of sediments.
- **Interpret**:
  - how microbial factory works (shallow vs deep methane generation)
  - How are the products transported to the deposit
- **Elucidate** system behavior of entire carbon cycle

‘23 UT-GOM2-2 Expedition Options

Increase Science, Reduce Risk

+ 2nd Coring hole and more cores

Adds:
- Redundancy and improved interpretations

+ Spot Pressure Coring

Explores:
- How microbial gas is distributed
- How hydrate deposits form
- Additional hydrate bearing sands.

+Add Conventional Coring and PT measurement

Explores:
- Where and how microbial gas forms
- Age and residence time of fluids
- How hydrates impact climate cycle

Minimum Plan

H002

w/ 10 Pressure cores of a hydrate-bearing sand

- Characterize hydrate reservoir
- Subsequent research illuminates methodologies for potential production

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H002

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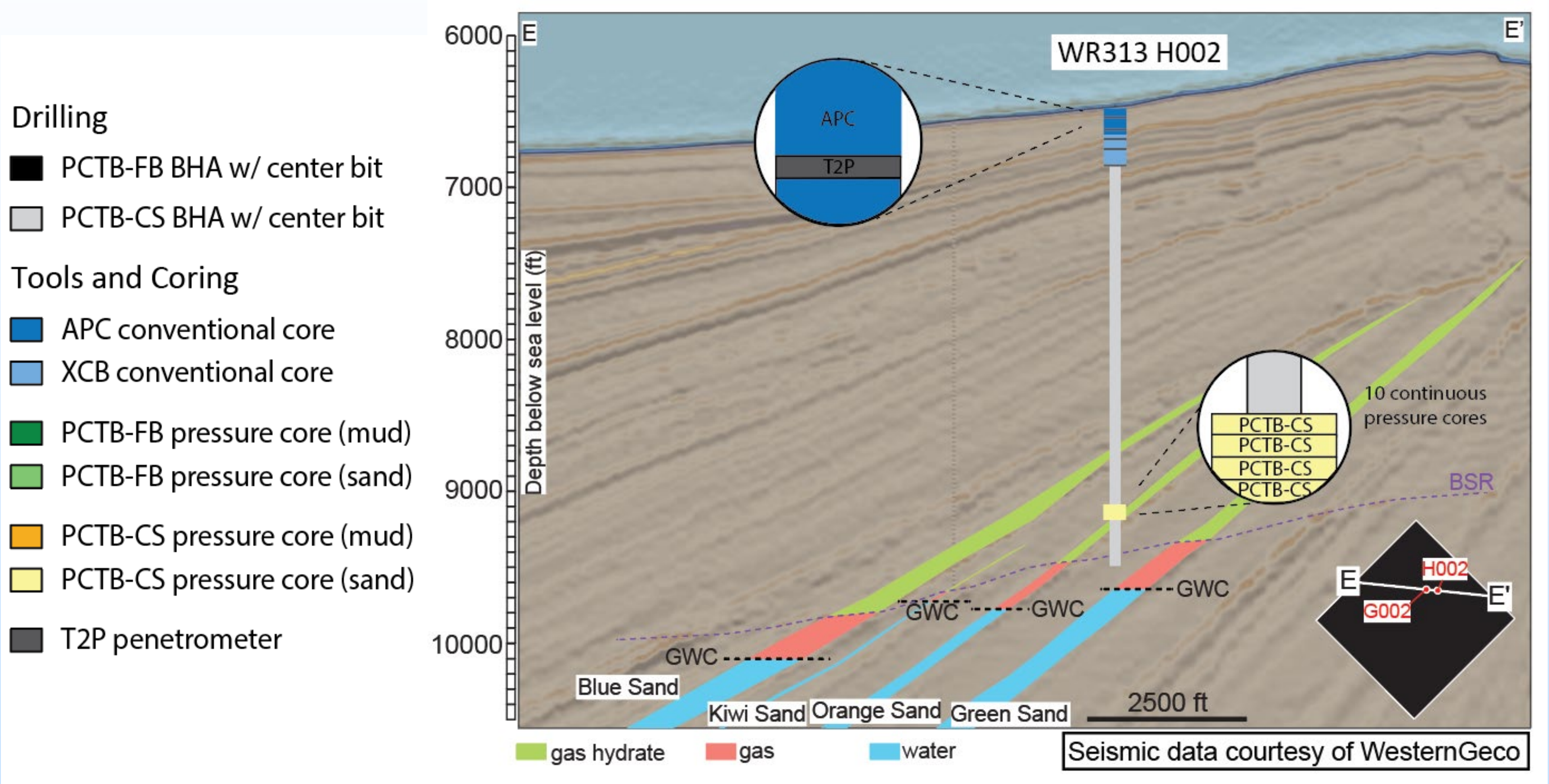
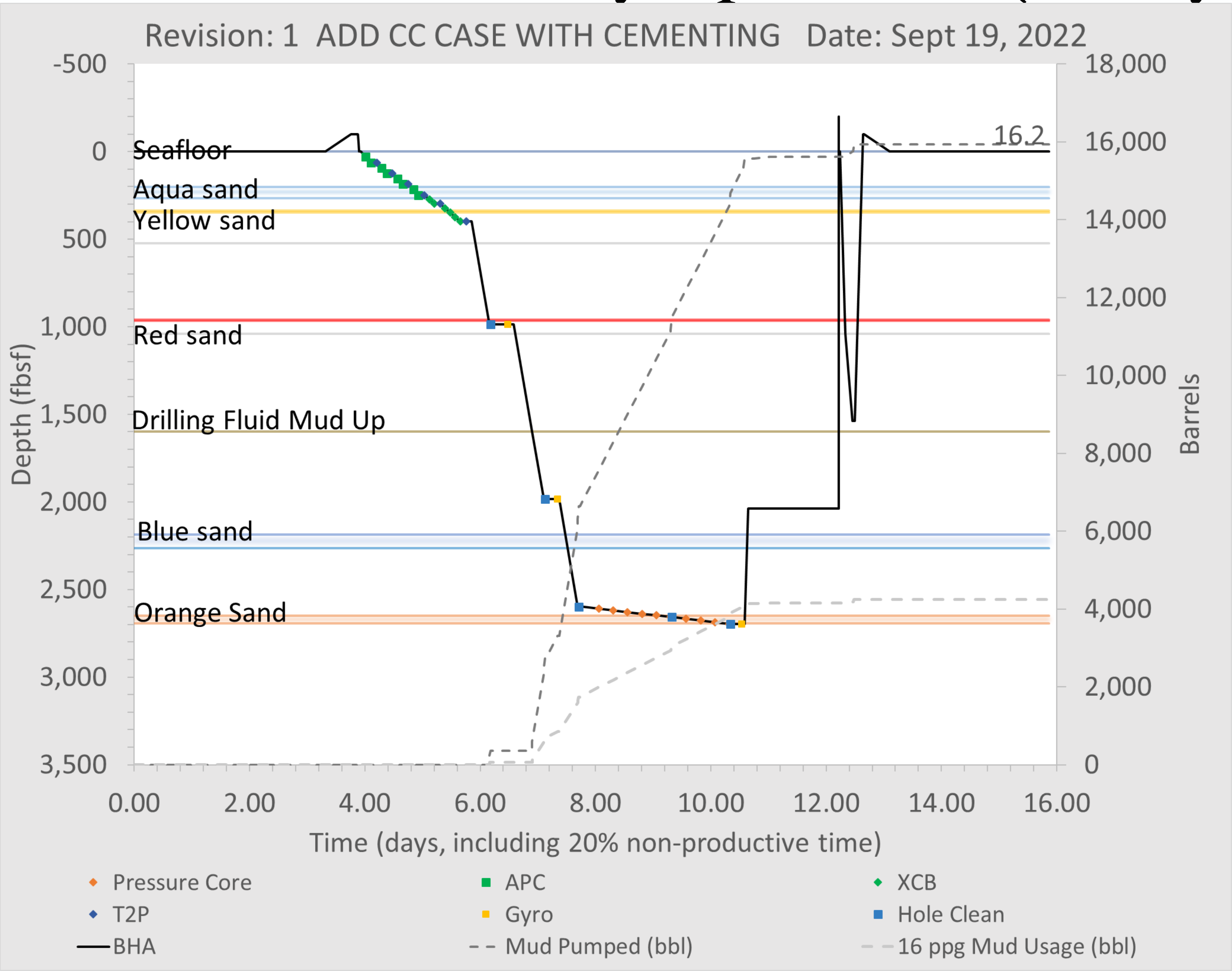
UT-GOM2-2 Current Most-likely Operations



UT-GOM2-2 Most-likely Operations (16 Days)



Challenges

1) Permitting (13 different permits, many have to be repeated)
2) Contracting, Insurance, Bonding, UT Approval
3) Drill hole ~3,000 feet (~900 m) below mudline in 6460' water depth
   - ~14,000 bbl. mud
   - 10,000 ft of pipe
   - Plug and Abandon
4) Conventional core, pressure core, direct pressure and temperature measurements.
5) Mobilize and perform science program twice (at sea and dock)
   1) 10 portable laboratories
   2) 32 scientists, 6 subcontracts, 3 service agreements
   3) Helix Q-4000 and 15 partner organizations
6) Continuous re-assessment of budget and science tradeoffs, before and during expedition.

UT-GOM2-2 Science Team

Pressure
Core Analysis

Seismic
Gas Analysis

Geomechanics

Sedimentology

Microbiology

In situ Pressure
and Temperature

Pressure Core Analysis;
Geomechanics

Regional Mapping,
Permitting Support

Pore Water Geochemistry

Core Analysis

Geological and Geophysical Analysis, Project Management, Pressure Coring

UT-GOM2-2 Operations

TR Consulting Inc; Pettigrew Engineering

Safety and Operations

GEO TEK

Coring and T2P Deployment

PLI PRO-LOG, INC.

Science Labs

Helix ENERGY SOLUTIONS

Vessel and Rig Operations

BSEE submissions

Schlumberger

Wireline and Cementing

MI SWACO

Drilling Fluids

WORKSTRINGS INTERNATIONAL
A SUPERIOR ENERGY SERVICES COMPANY

Drill String

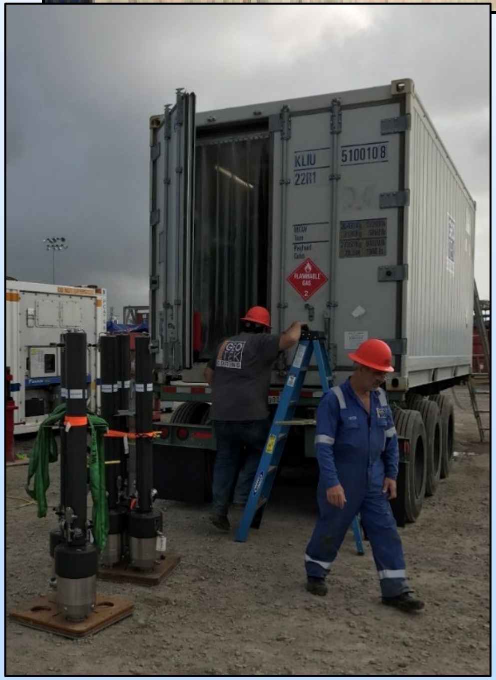
HOS HORNBECK OFFSHORE
Service with Energy

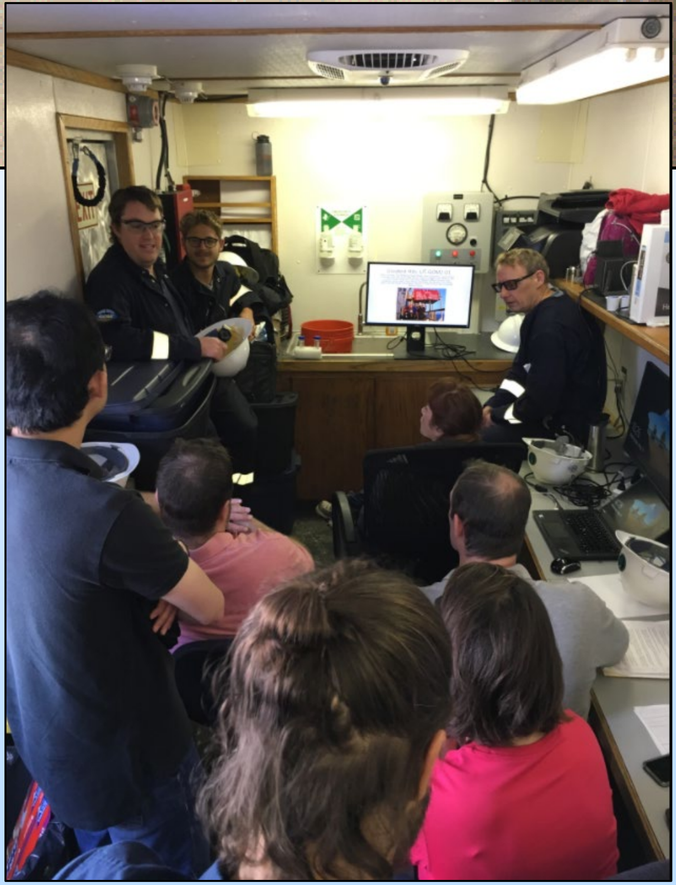
Logistics

UT-GOM2-2 Out on the *Q-4000*

View from above the Top-Drive

UT-GOM2-2 ‘Dockside’ Core Analysis

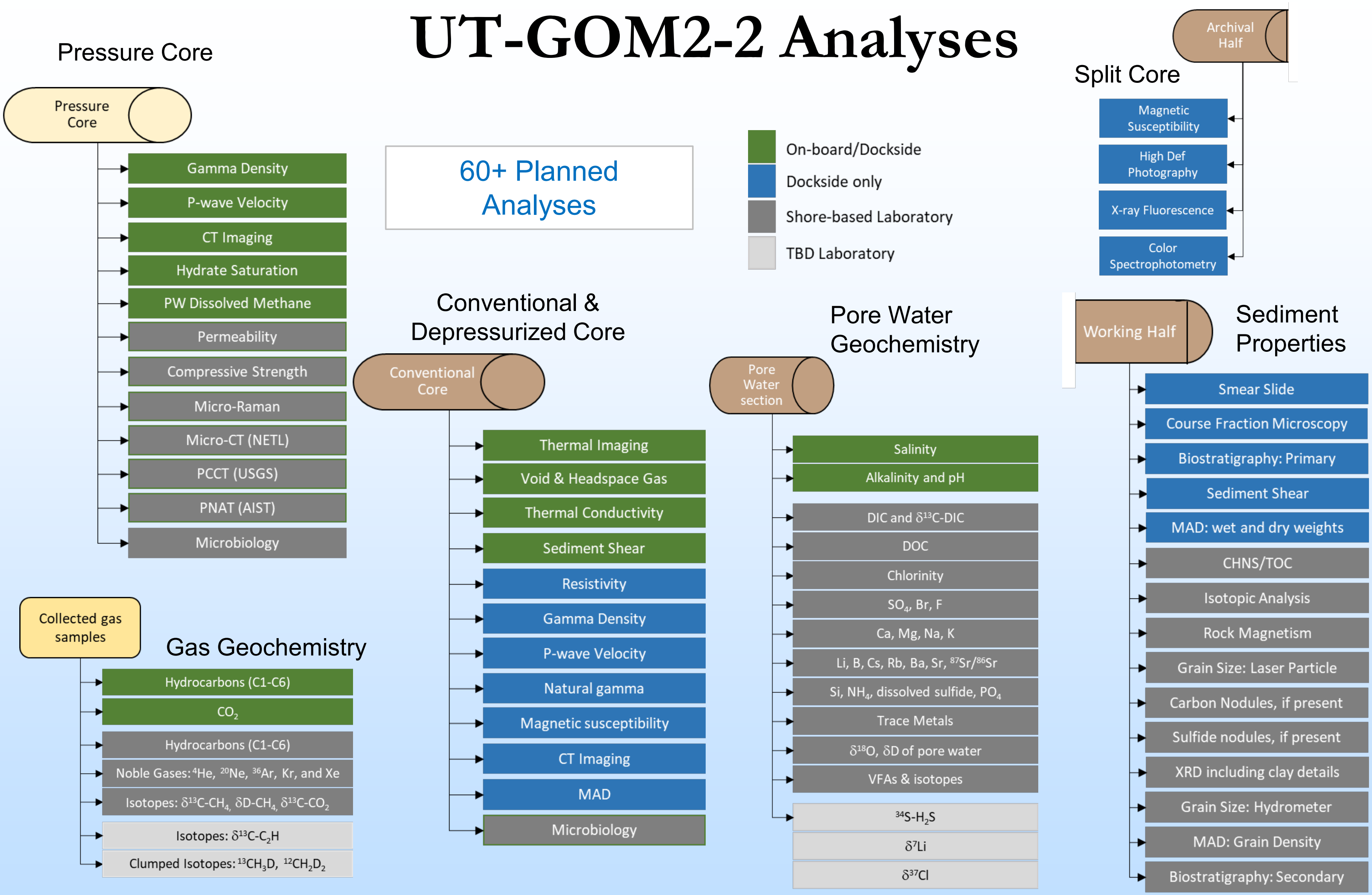




Areas for:

- Pressure Core Processing and Analysis
- Quantitative Degassing
- Pressure Core Transport
  Conventional Core Processing and Analysis
- Pore Water Squeezing and Analysis
- Preservation of Microbiology, M&D, Void Gas, and Headspace gas samples
- Whole Core Scanning
- Thermal Conductivity and Sediment Strength
- Split Core Scanning
- Spit Core Layout
- Spit Core Sampling

UT-GOM2-2 Analyses



UT-GOM2-2 Website

Find:

- Prospectus
- Sample Requests
- Science Party Updates
- Post-Expedition Publications


UT-GOM2-2: Gulf of Mexico Deepwater Hydrate Coring Expedition

EXPEDITION HOME | EXPEDITION PROCEEDINGS | PROJECT HOME

Expedition UT-GOM2-2 General Information

Location: Terrebonne Basin, northern Gulf of Mexico
Sites: WR313 H002 and WR313 H003
Dates: January – May, 2023
Chief Scientist: Peter Flemings
Sponsor: U.S. Department of Energy

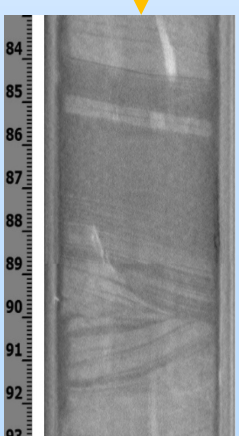
Expedition Summary & Scientific Objectives

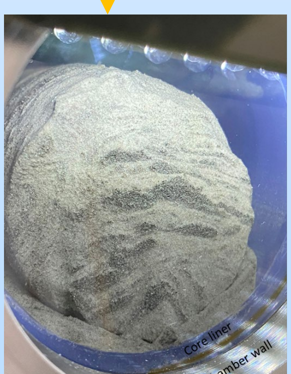
The University of Texas at Austin (UT), Genesis of Methane Hydrate in Coarse-Grained Systems: Northern Gulf of Mexico Slope Project (GOM2), will perform the UT-GOM2-2 drilling and coring expedition in the Terrebonne Basin, Gulf of Mexico outer continental shelf.

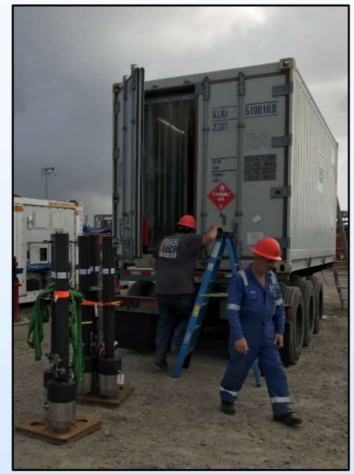
https://ig.utexas.edu/energy/gom2-methane-hydrates-at-the-university-of-texas/gom2-2-expedition/

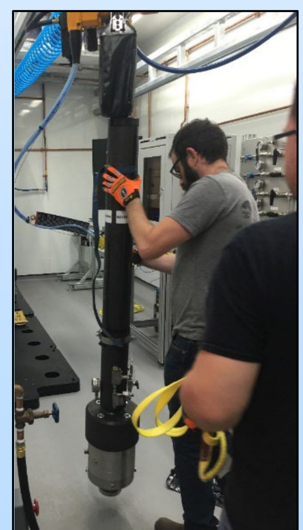
Hydrate Science: Bringing it home

Pressure core sampling and identification → Scientific effort at the dock → Transport to UT → Years of experimentation at institutions



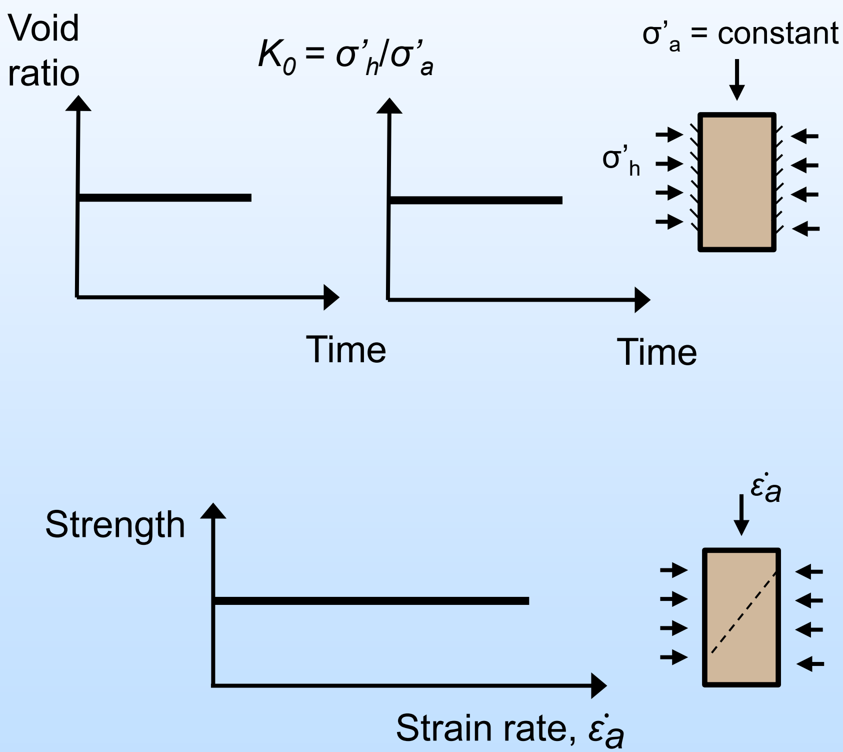




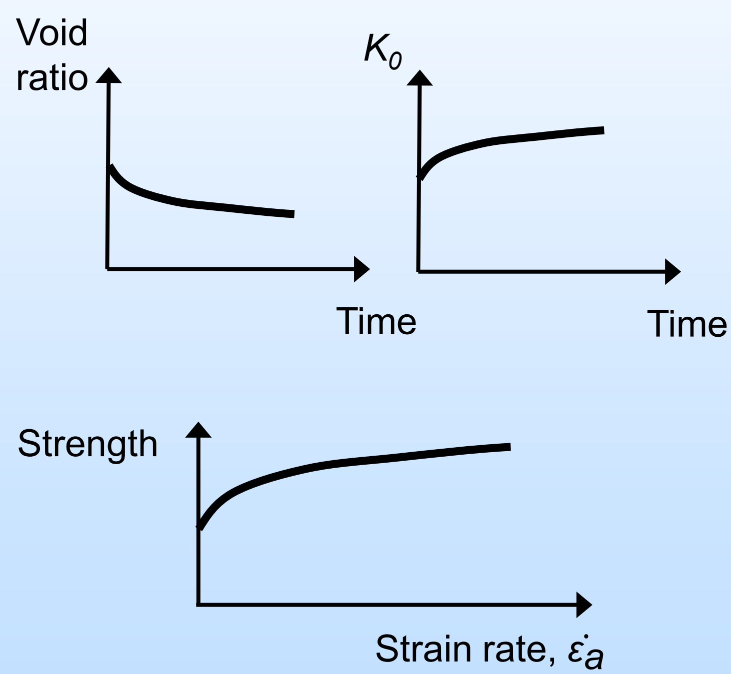


Science: Hydrates as Visco-Plastic Materials

No-time dependency
traditional geotechnical model

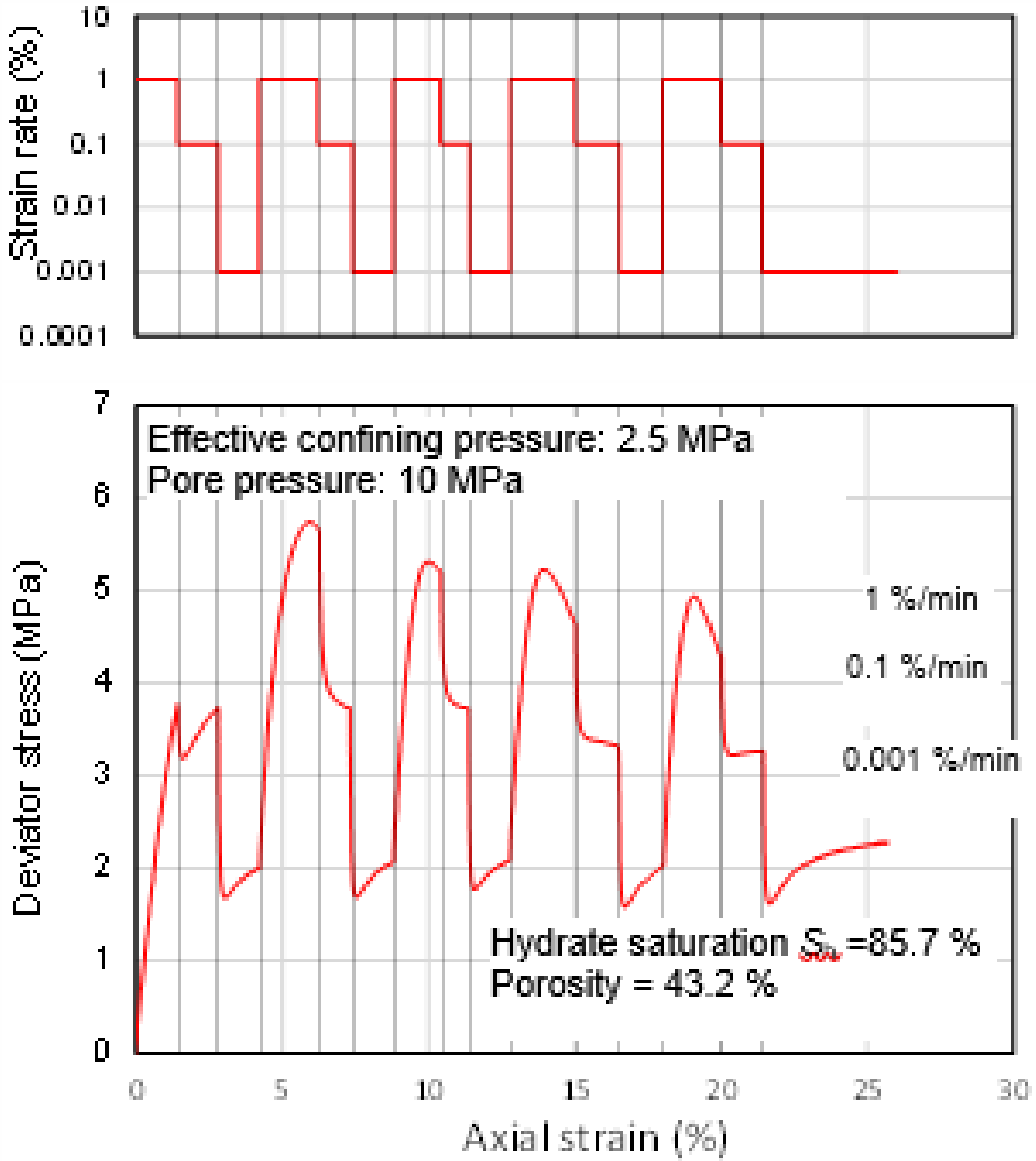


Time dependency
visco-plastic material



Material behavior can depend on time or strain rate

Visco-plastic behavior



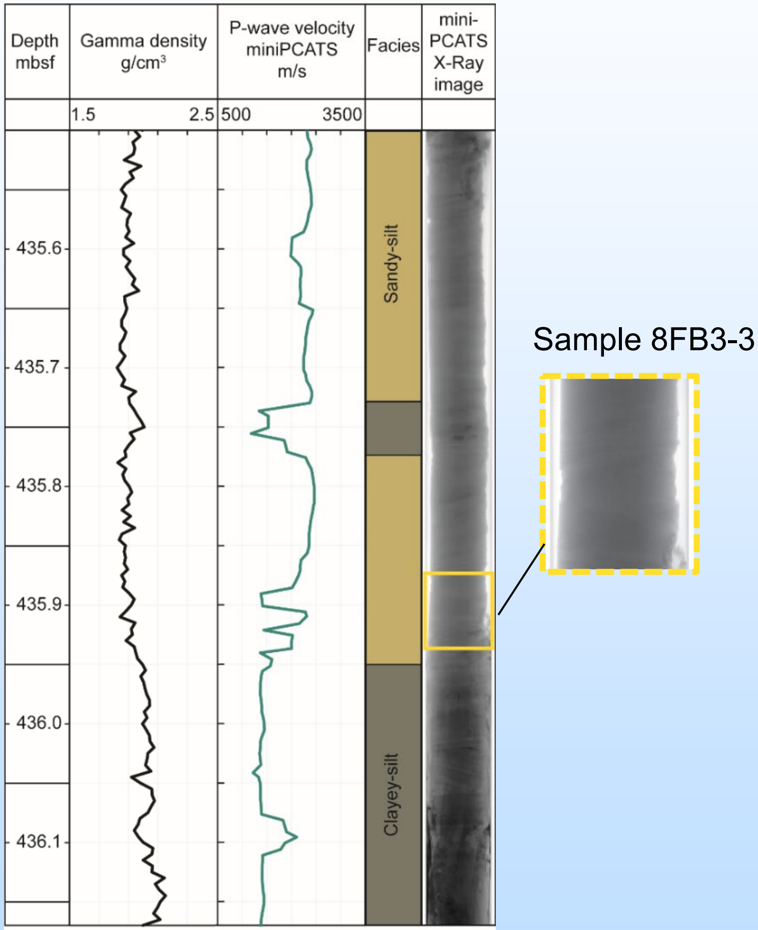
(Yoneda et al. 2022)

Our previous work showed:

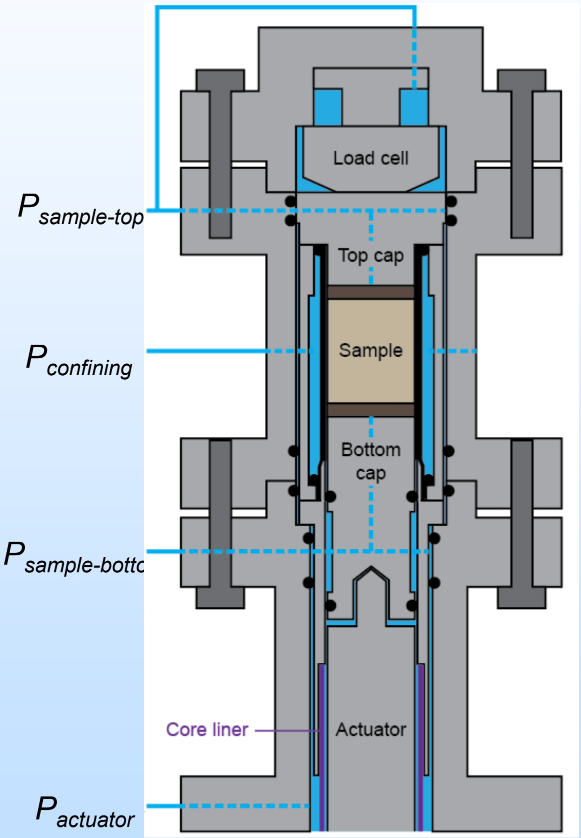
- Strain-rate dependency for material behavior
- Horizontal stresses increase with hydrate saturation (Fang et al. 2022)

Visco-plastic behavior

Sample selection



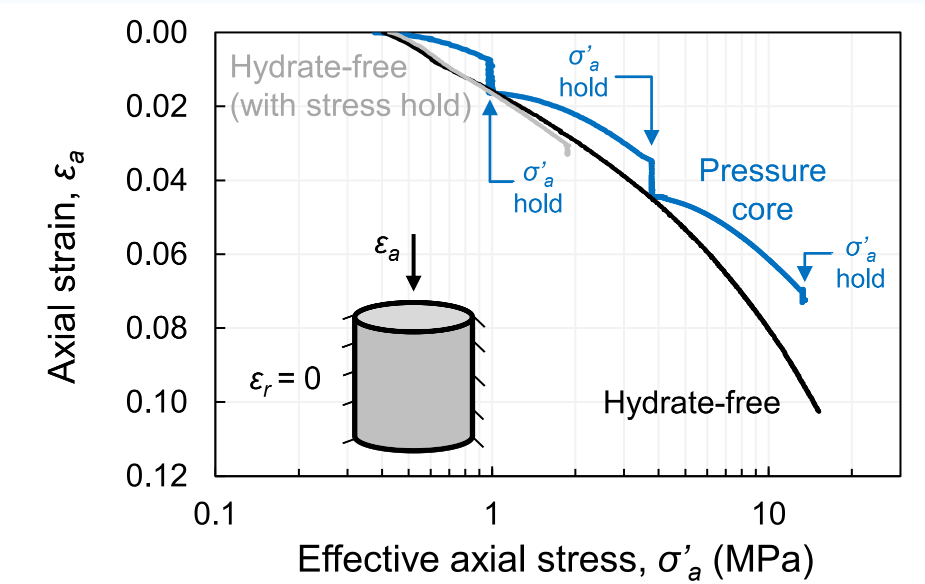
Test device



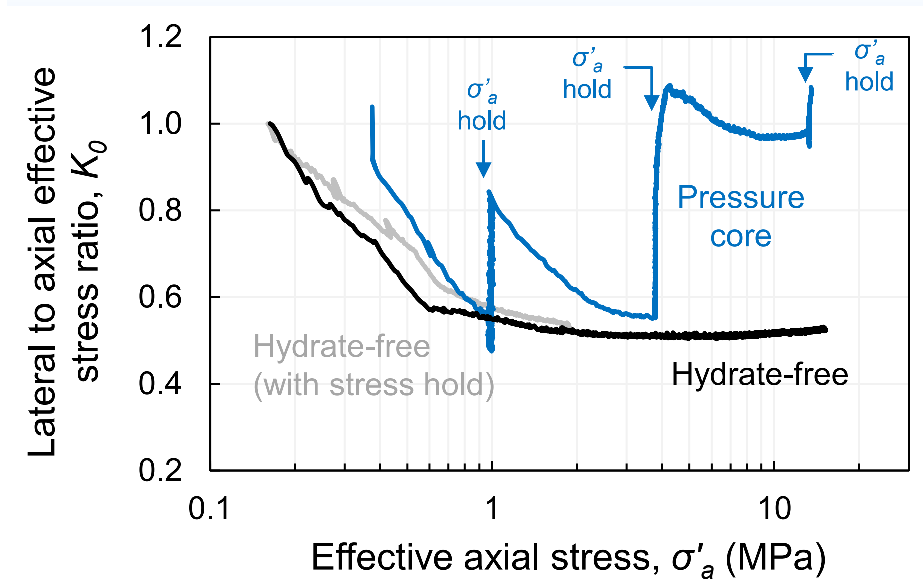
We explored further the viscoplastic behavior through geomechanical tests in GC955 pressure core samples

Visco-plastic behavior

Compression



Stress ratio, K_0



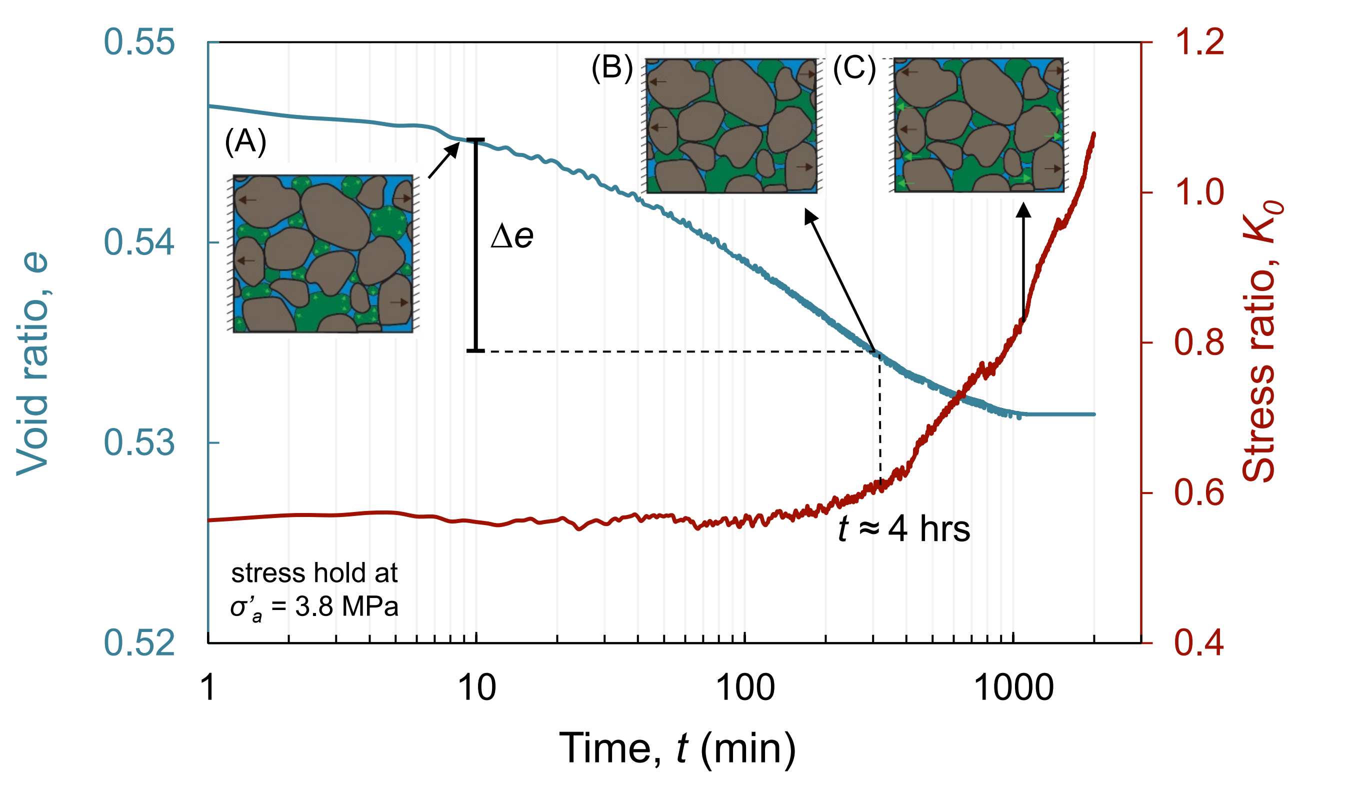
- We conducted constant rate uniaxial strain experiments (CRS) and measure the stress ratio K0, including lengthy axial stress hold periods.

- Hydrate-bearing sediments behave visco-plastically:
  - The sediment compresses significantly during the stress holds
  - The stress ratio K_0 increases during stress holds, converging to isotropic conditions.

(Cardona et al., under review)

Visco-plastic behavior

Time-scales: deformation and stresses



K_0 increases at t ~ 4 hrs, after a significant deformation Δe has occurred. We envision:

(A) The hydrate is load-bearing and deforms, but does not exert stresses laterally

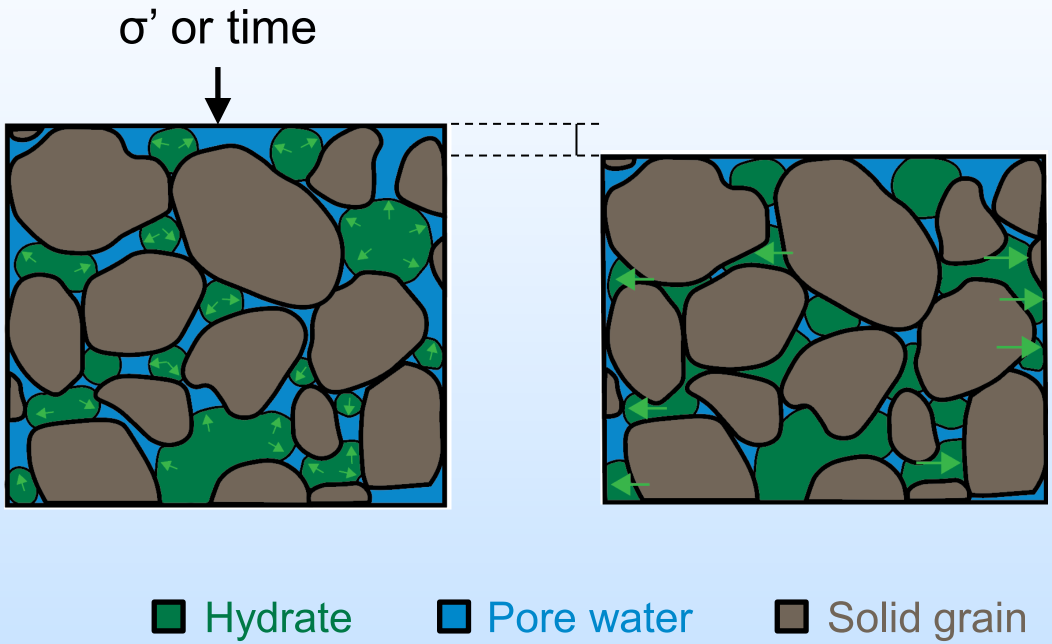
(B) Limited space to deform: deformation rate decreases and K_0 increases.

(C) The hydrate pushes sideways and K_0 continues to rise

(Cardona et al., under review)

Visco-plastic behavior

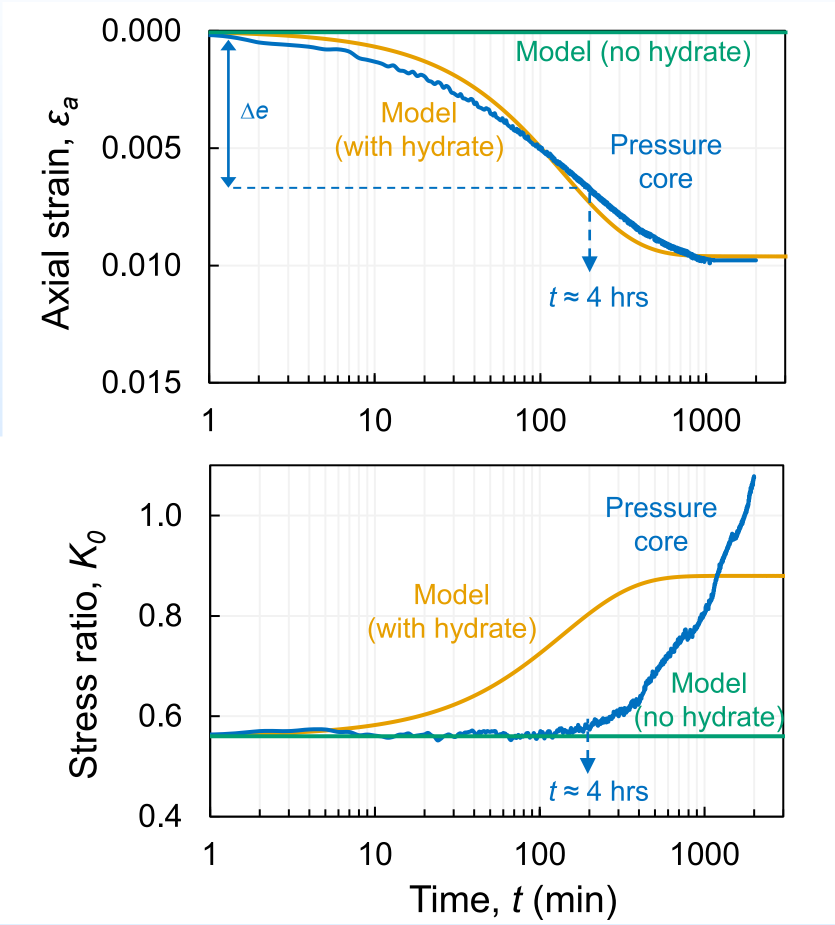
Hydrate-bearing sediments micromechanical view

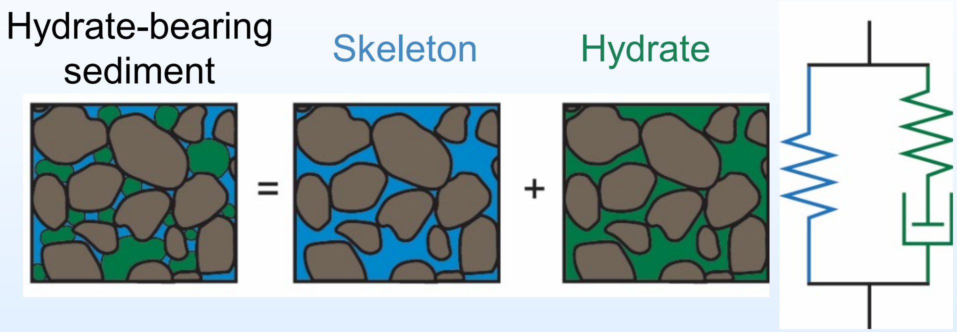


- **We envision the hydrate is a viscoplastic medium**
- **The hydrate is load-bearing:**
  - **Flows viscously and expels pore water**
  - **Remains trapped upon compression**
  - **Transfers the load laterally**

Visco-plastic behavior

Modeling the behavior of hydrate-bearing sediments



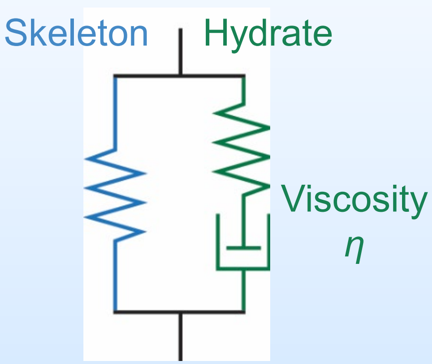


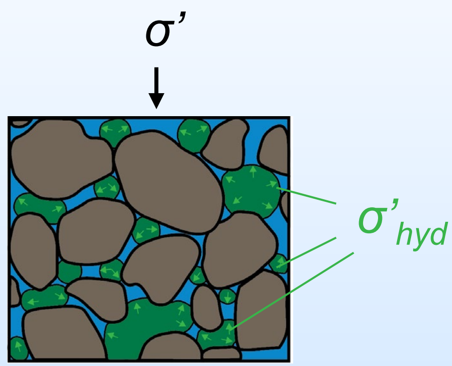
- Linear solid model (spring and dashpot)
- Model accurately predicts compression trends and highlight the deformation is related to viscous hydrate flow.
- Complex interplay between deformation and K_0 is not captured

(Cardona et al., under review)

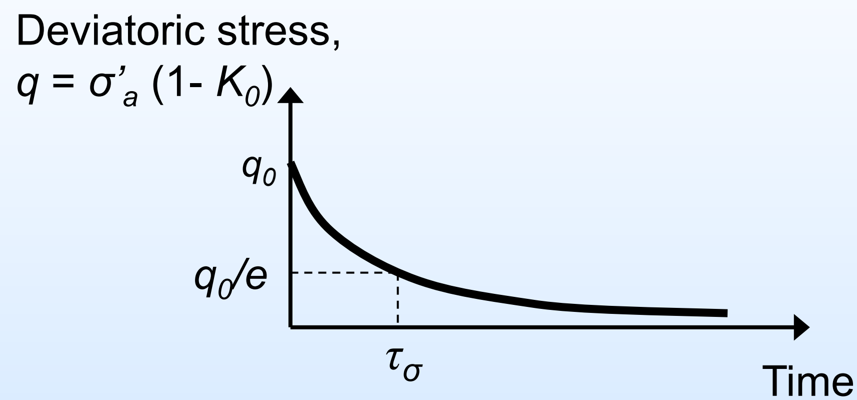
Visco-plastic behavior

Hydrate viscosity





Time-scale for relaxation



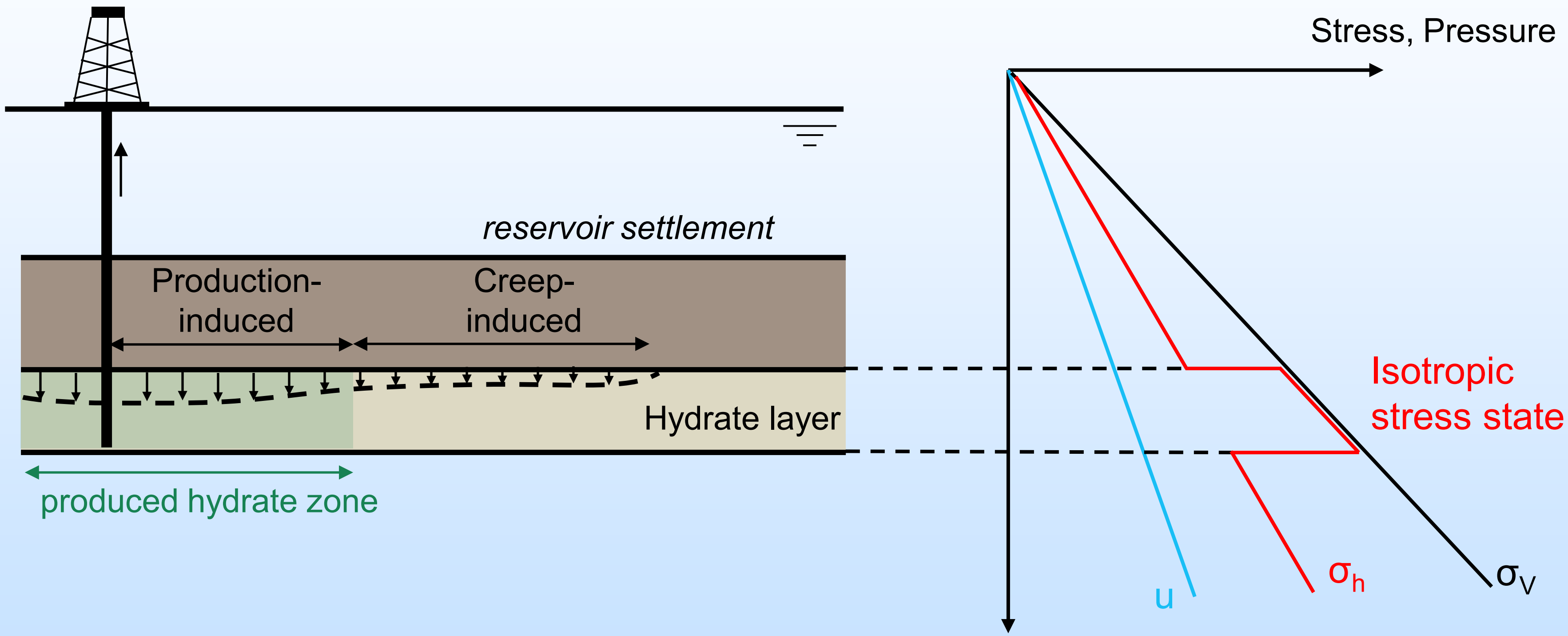
- **Model viscosity: η = 1.2×10^{11} Pa.s**
- **Pure hydrate ≈ 2×10^{13} Pa.s (Durham et al., 2003)**
- **Pressure cores ≈ 2×10^{10} Pa.s (Yoneda et al., 2022)**
- **Stress concentration in porous media hydrate implies $\sigma'_{hyd} > \sigma'$ and may explain lower viscosity values in sediments**

Stress hold (MPa)	Relaxation time, τ_σ (hrs)
σ'_a = 1	25
σ'_a = 3.8	18
σ'_a = 13	1

(Cardona et al., under review)

Visco-plastic behavior

Implications: creep and high in-situ stresses



- **Reservoir settlement far from the wellbore after production has ceased: unproduced hydrate can creep.**
- **In-situ stresses in hydrate-bearing layers may be isotropic**
  - **affects completion and drilling strategies (e.g., excessive torque, pack-offs, casing collapse).**

Project Summary

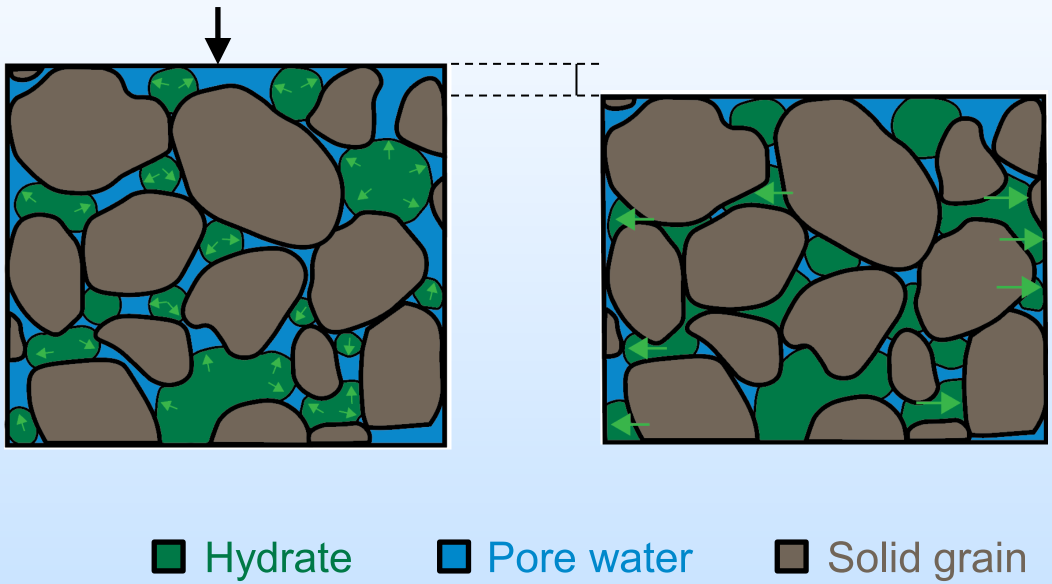
- **Science program** to elucidate hydrate reservoir behavior and basin scale carbon cycle.
  - Energy, response to climate change, role of hydrates in carbon cycle
- **Big Science & Engineering:** complicated planning, logistics, and execution. High risk.
- **Technical Results:** One example: new insight into visco-plastic material behavior of hydrate reservoirs that will feed into simulation models of the hydrate reservoir.

Thank you!

Visco-plastic behavior

Hydrate-bearing sediments micromechanical view

σ’ or time



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GOM2 Objectives

- To locate, drill, and sample methane hydrate deposits
- To store, manipulate, and analyze pressurized hydrates samples
- To maximize science through sample distribution, analysis, and collaboration

UT-GOM2-1
Marine Field Test
GC 955

- Obtain and Equip Pressure Core Center
- Modification and Testing of Coring equipment

- Test deep-water pressure coring
- Test pressure core transport and handling
- Test scientific procedures
- Tests analysis capabilities
- GC955 characterization
- Sample distribution and analysis
- Workshops and publications

- Modification and Testing of coring equipment
- Core preservation
- Expedition Planning

UT-GOM2-2
Scientific Expedition
WR 313

- Characterize GOM hydrate-bearing sands

TBD:

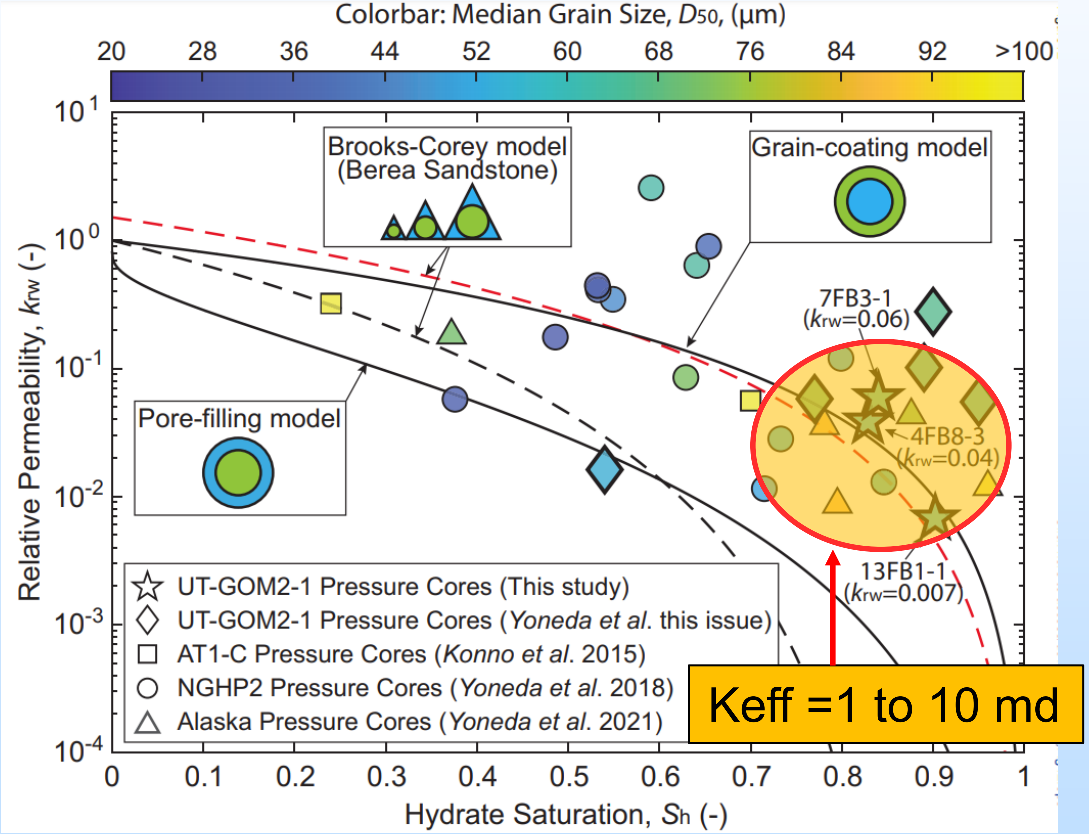
- Geochemical profile
- Measurement of in-situ pressure, temperature
- Dissolved methane and gas composition

2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
Phase 1 10/14-09/15	Phase 2 10/15-01/18	Phase 3 01/18-09/19	Phase 4 10/19-09/20	Phase 5 10/20-09/23	Phase 6 10/23-09/25						

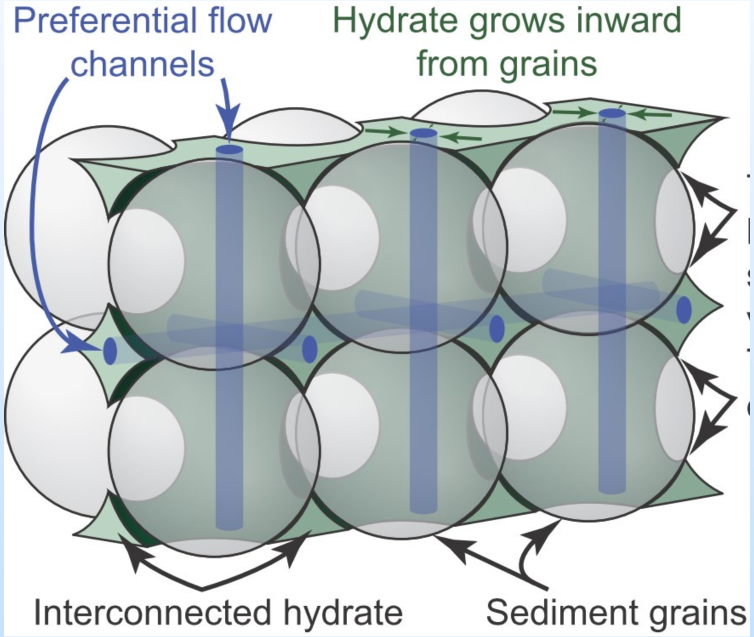
Current Status

High Effective Permeability

old slide from 2021 presentation



(Fang et al., in press)

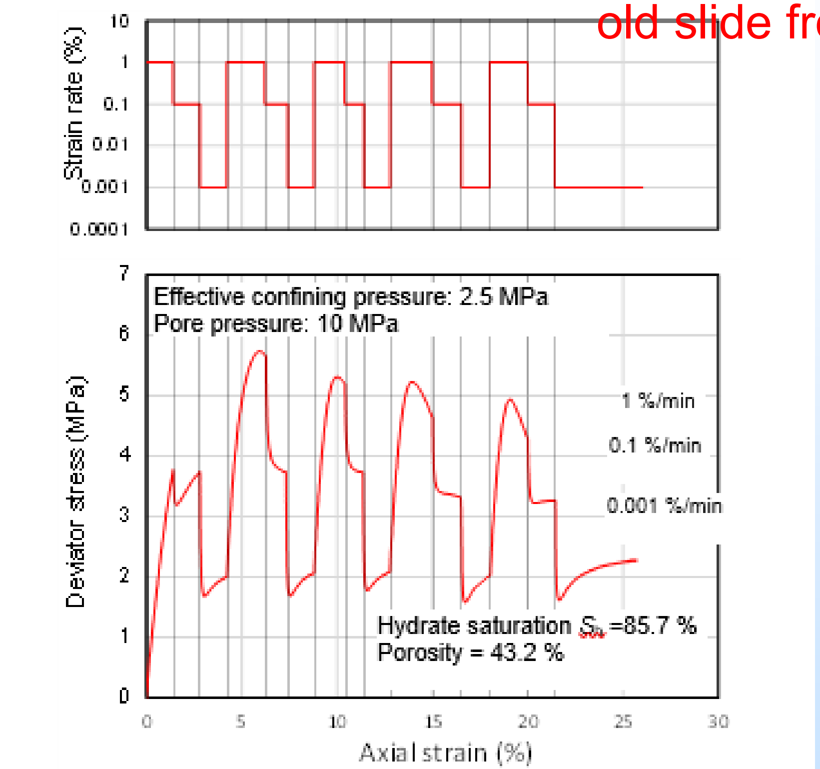


(Yoneda et al., in press)

Visco-elastic behavior

Hydrate strength strain rate dependent

old slide from 2021 presentation



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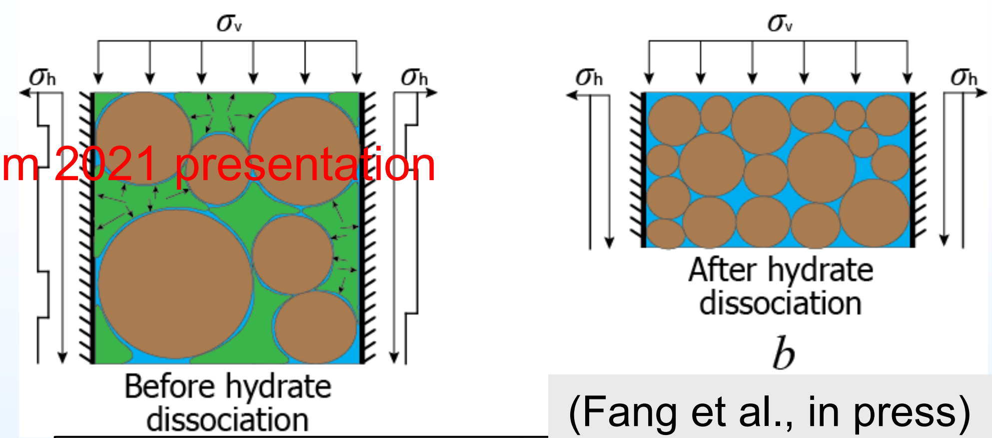

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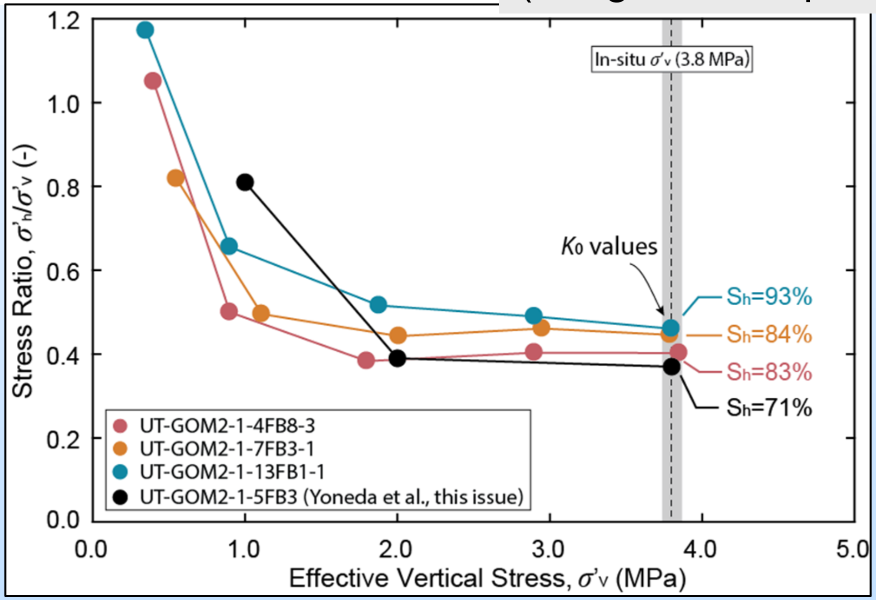


Commonly described by flow law:

$$\dot{\varepsilon} = A_0 exp\left[-\frac{Q}{K_c T}\right] q^b.$$

Higher lateral stress in hydrate reservoirs

- Impacts stress state

Hydrate can be load-bearing

- compaction during production

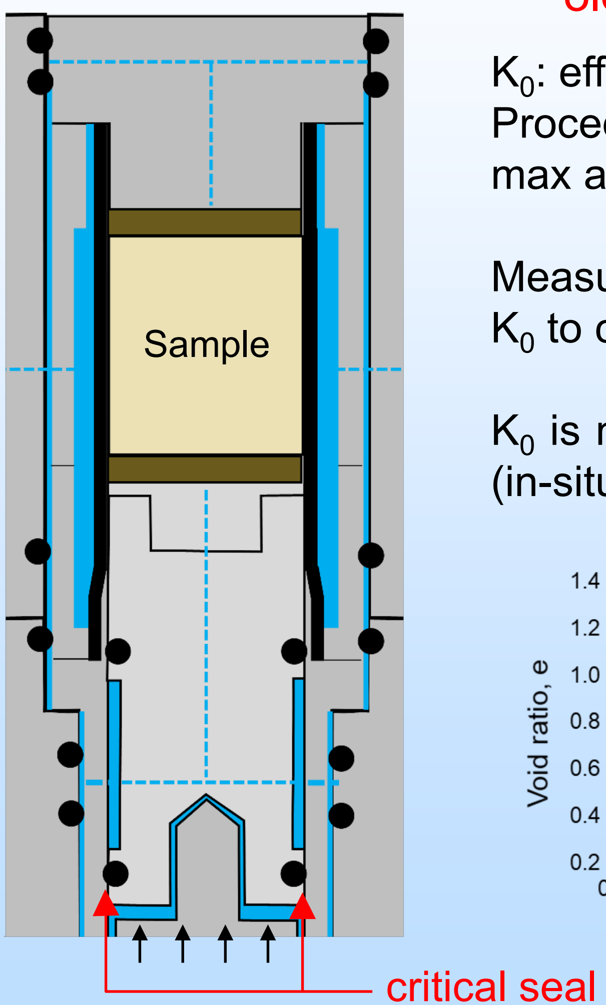
Technology Development
Pressure Core Geomechanical Testing

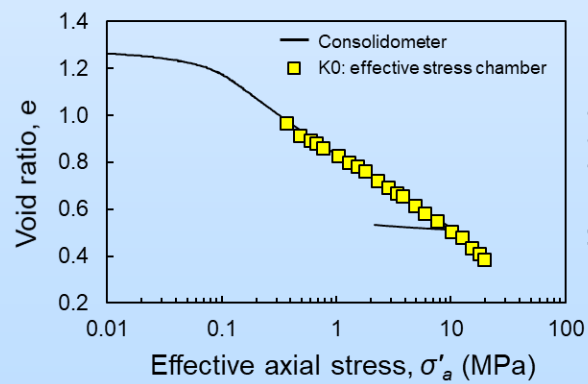
old backup slide from 2021 presentation

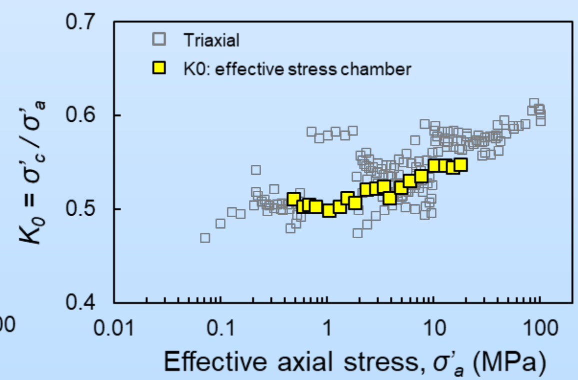
K_0: effective stress chamber
Procedures and seal rings were modified to increase the max applied effective stress from 4 to 20 MPa.

Measurements were validated by comparing results from K_0 to classical devices.

K_0 is now able to characterize UT-GOM2-2 pressure cores (in-situ stress levels ~10 MPa)

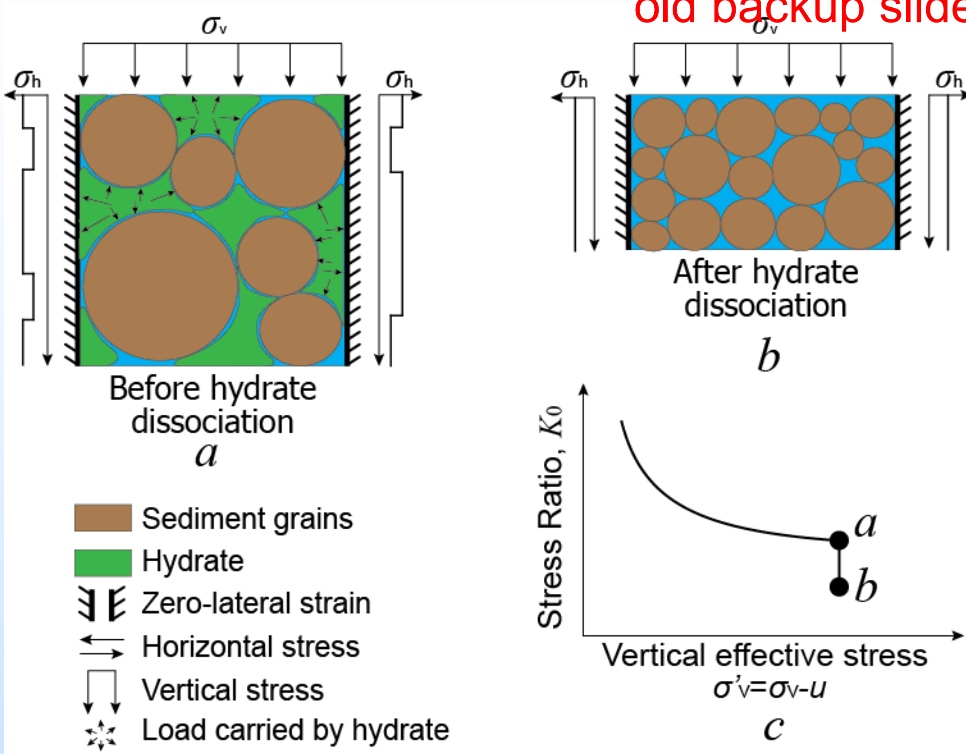




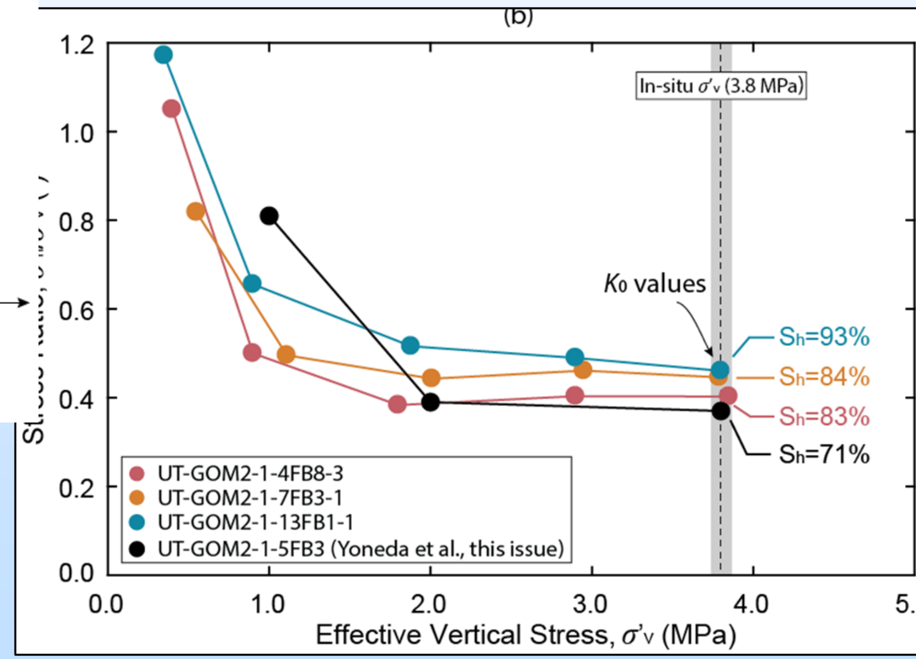


Visco-elastic behavior

old backup slide from 2021 presentation



Stress Ratio (K_0) proportional to hydrate saturation



(Fang et al., in press)

Hydrate is viscous fluid phase that cannot escape the pore space during the compression.

It bears the load during compression.

(Yoneda et al. in press)

'23 UT-GOM2-2 Expedition Options

Expedition will be rebalanced with every increase to
- Maximize Science
- Better leverage operational costs
- Reduce risk

Add 2nd Coring hole and more cores
+$5M

Funds
- Flexibility
- Redundancy, improved interpretations
- More post-cruise science at all institutions

Add Spot Pressure Coring
+$5M

Funds understanding of:
- How the microbial gas system works
- Exploration models for finding microbial gas deposits
- Characterization of additional hydrate bearing sands
- Role of marine mud microbial gas in the climate cycle

Better Leverages
- Development of gas sampling and analysis capability since 2014

Add Conventional Coring and PT measurement
+$10M

Most likely as of Fall'22

Funds illumination of:
- Processes by which hydrates form
- How the microbial gas model works-microbiology
- Exploration models for finding hydrate deposits
- Role of hydrates in the climate cycle

Leverages
- Investment in microbiology, sedimentology, water geochemistry, geomechanics since 2014

H002
w/ 10 Pressure cores of a hydrate-bearing sand
$16.5M* overall
+$5M over FY22 funds

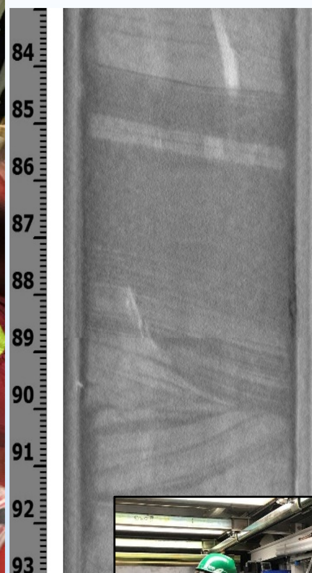
Funds
- Characterization of the hydrate reservoir
- Subsequent research illuminates methodologies for potential production

Leverages
- $14M 2017 expedition, UT-GOM2-1 pressure coring test
- $14M seismic and well data
- $9M DOE pressure coring/technology development
- $Developing UT ($2M), NETL, and USGS Woods Hole pressure core analysis capability
- $30M Incurred effort by staff, students, and administration

*July 28, 2022 expedition estimate, does not include required effort/field pay, expedition travel, post-expedition analysis or UT F&A.

Bringing it home

On-board → Huge Scientific effort at the dock → Transport to UT → Years of experimentation at UT



UT-GOM2-2 Permits

AGENCY	REQUIREMENT	
BOEM	Qualified Operator Certification	Complete
BOEM	BOEM Qualification Update	Complete
BOEM	Lease Bond	Complete
BOEM	Right-of-Use and Easement (RUE)	Complete
BOEM	Initial Exploration Plan	Complete
BOEM	Revised Exploration Plan	Complete
LDNR	CZM Consistency Cert.	Complete
US DOE	NEPA Environmental Questionnaire (EQ)	Complete
BOEM	Permit to Conduct Geological or Geophysical Exploration for Mineral Resources or Scientific Research on the OCS	Pending
BSEE	Application for Permit to Drill (APD)	Pending
BSEE	Application for Permit to Modify (APM)	Pending
US CG	Letter of Determination (LOD)	Pending
US EPA	NPDES Electronic Notice of Intent (eNOI)	Pending

UT-GOM2-2 Partners

Pressure
Core Analysis

Science

GEO TEK

Pressure
Core Analysis

University of New Hampshire

Sedimentology

Tufts University

Geomechanics

In situ Pressure
and Temperature

Colorado School of Mines 1874

Ohio State

Seismic
Gas Analysis

Oregon State University

Microbiology

Pore Water
Geochemistry

Operations

TR Consulting Inc;
Pettigrew Engineering

Safety and Operations

GEO TEK

Coring and T2P Deployment

Helix ENERGY SOLUTIONS

Vessel and Rig Operations

BSEE
submissions

MI SWACO

Drilling Fluids

Workstrings International — A Superior Energy Services Company

Drill String

Schlumberger

Wireline and Cementing

HORNBECK OFFSHORE — Service with Energy

Logistics

Alejandro, I’d like to include a really basic slide about rheology here.
On the left I’d like to have ‘the traditional geotechnical model’. That model shows strength independent of strain rate. Under uniaxial loading it shows a constant ratio of horizontal to vertical effective stress. It shows no creep during stress holds.

In contrast, on the right side, I’d like to see a discussion of the rheology of visco-plastic material. These should all be simple cartoons or sketches.

I’d also like to see on this slide or the next one, the grain scale cartoon you have in your paper, that illustrates the role of the hydrate in the pores and our cartoon vision of how it is working.