TEXAS Geosciences
The University of Texas at Austin
Jackson School of Geosciences
Institute for Geophysics

NATIONAL ENERGY TECHNOLOGY LABORATORY

U.S. DEPARTMENT OF ENERGY

Deepwater Methane Hydrate Characterization and Scientific Assessment

Peter Flemings & the GOM2 Team

The University of Texas at Austin

Lamont-Doherty Earth Observatory

Oregon State University

The Ohio State University

University of New Hampshire

University of Washington

Pettigrew Engineering

Geotek Ltd.

UT-GOM^2

U.S. Department of Energy

National Energy Technology Laboratory
Methane Hydrates Project Review Meeting

Dec 1, 2020, 3:15 PM EST

Presentation Outline

1. Introduction
2. UT-GOM2-1 Green Canyon 955
3. Pressure Coring/Core Technology Development
4. UT-GOM2-2 Walker Ridge 313

Deepwater Methane Hydrate Characterization and Scientific Assessment (DE-FE0023919)

GOM2 Objectives

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

UT-GOM2-1
Marine Test
GC 955

- Test of deep-water pressure coring
- Test of Pressure core transport and handling
- Test of scientific procedures

UT-GOM2-2
Scientific Expedition
WR 313

- Characterization of GOM hydrate-bearing sands
- Comparison within a dipping sand
- Downhole Dissolved methane and gas composition
- Measurement of in-situ P-T
- Geochemical profile

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

- Tests of analysis capabilities
- GC 955 characterization
- Sample distribution and analysis
- Workshops and publications

- Modification and Testing of coring equipment
- Improved core preservation

2015	2016	2017	2018	2019	2020	2021	2022	2023	2024

- **Phase 1** 10/2014-09/2015
- **Phase 2** 10/2015-01/2018
- **Phase 3** 01/2018-09/2019
- **Phase 4** 10/2019-09/2020
- **Phase 5** 10/2020-09/2022
- **Phase 6** 10/2022-09/2024

Current Status

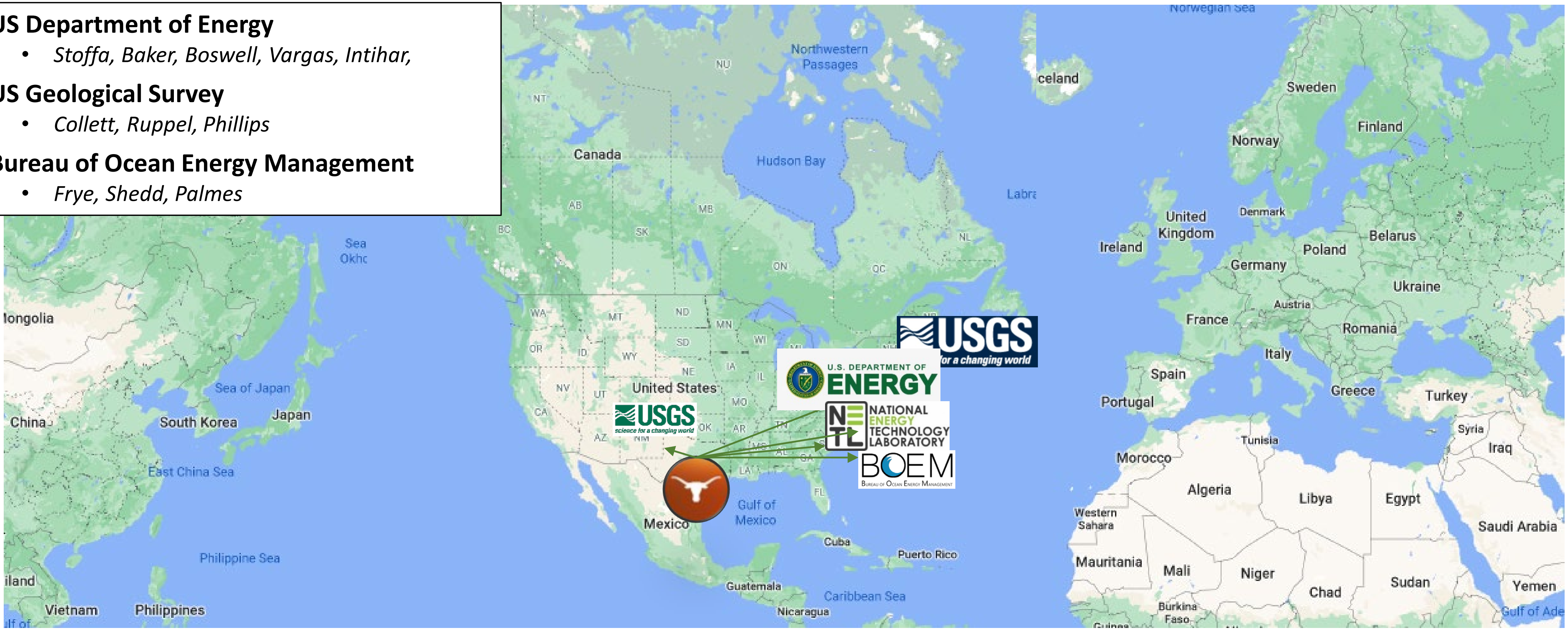
GOM2 Project Leads

- **The University of Texas at Austin**: *Peter Flemings*
  - Prime contractor, overall scientific and technical lead, experimental design, core handling/storage, hydrologic and geomechanical core analysis, GOM lease operator
- **Ohio State University**: *Ann Cook, Derek Sawyer*
  - Site characterization technical and science lead with added contributions in hole location determination, permitting, core analysis and geochemistry
- **LDEO**: *David Goldberg, Alberto Malinverno*
  - Wireline and LWD lead
- **University of New Hampshire**: *David Divins, Joel Johnson*
  - Lithostratigraphy lead
- **University of Washington**: *Evan Solomon*
  - Organic and inorganic geochemistry lead
- **Oregon State University**: *Fredrick Colwell*
  - Microbiology lead

- **Pettigrew Engineering:** *Tom Pettigrew*
  - Drilling operations lead
- **Geotek Ltd.:** *Peter Schultheiss, Mike Mimitz, Melanie Holland*
  - Pressure Coring Equipment lead

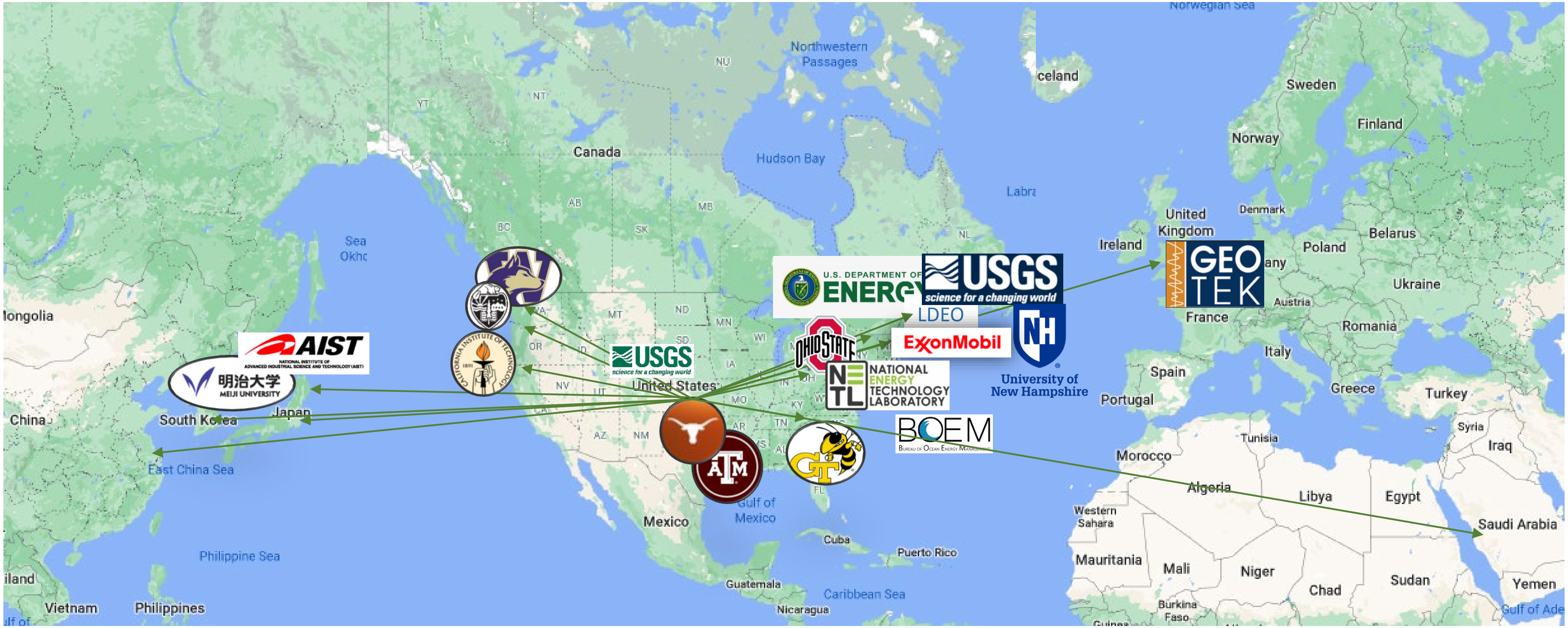
GOM2 Project Advisors

- **US Department of Energy**
  - *Stoffa, Baker, Boswell, Vargas, Intihar,*
- **US Geological Survey**
  - *Collett, Ruppel, Phillips*
- **Bureau of Ocean Energy Management**
  - *Frye, Shedd, Palmes*



GOM2 UT-GOM2-1 Sample Distribution

GOM2 All Collaborations

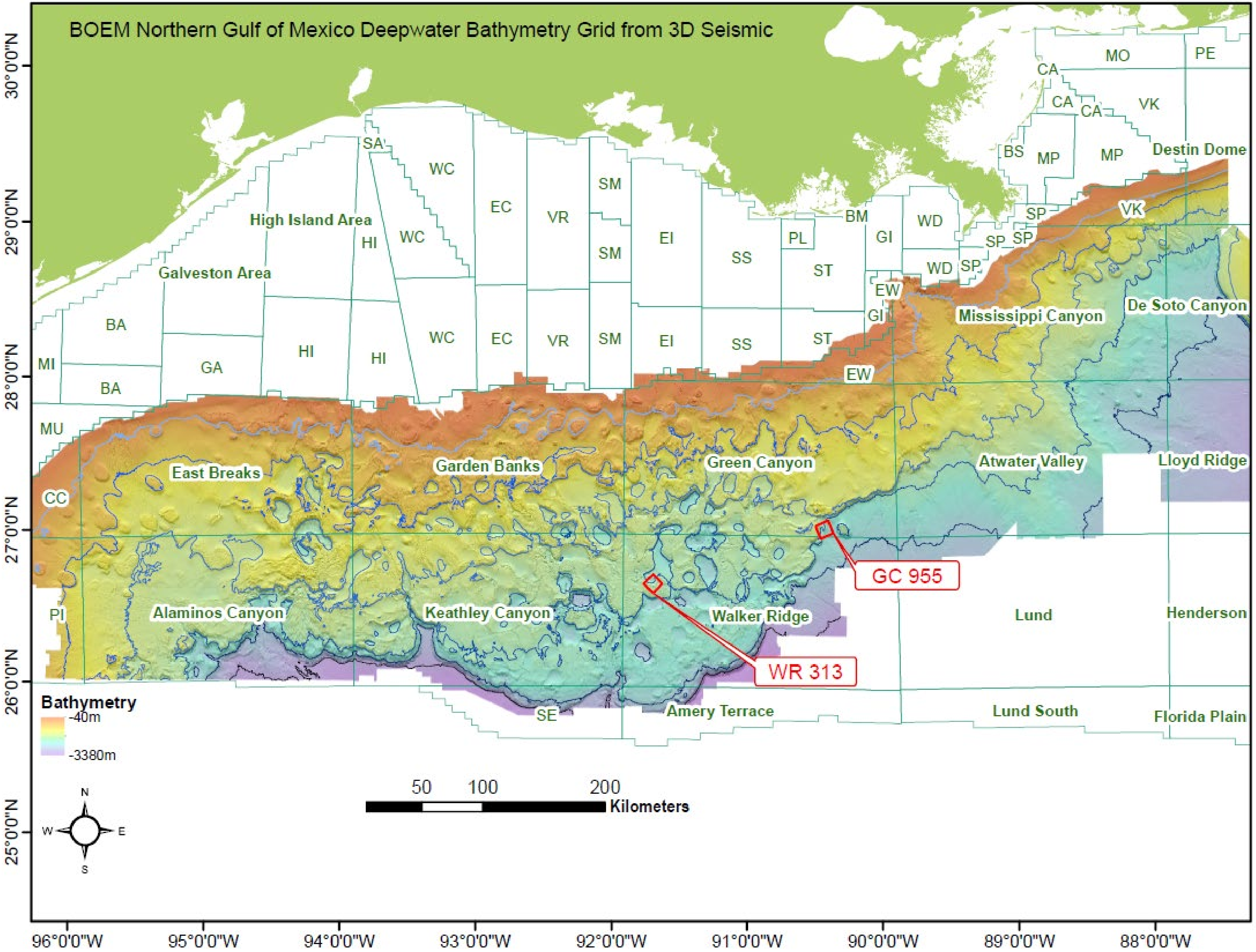


Key Accomplishments

- Successful Field Execution: GOM2-1
- Successful Collaborations
- Viable, and improving, pressure coring and pressure core testing technology
- Fundamental contributions in characterization, laboratory analysis, and modeling
- Dedicated volume summarizing our findings at GC 955
- International research collaboration on analyses of pressure core samples

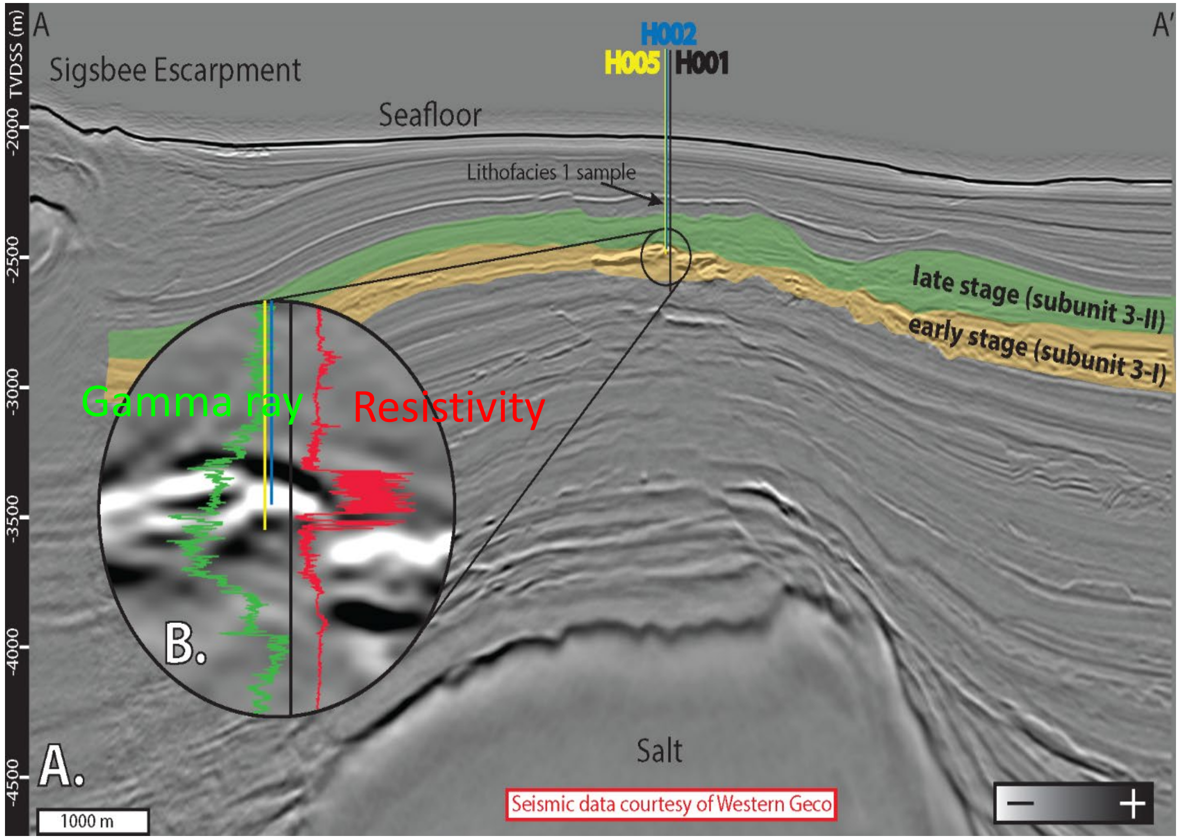
[AAPG Bulletin, Vol. 104 Number 9, Sept 2020]

GOM2 Field Locations

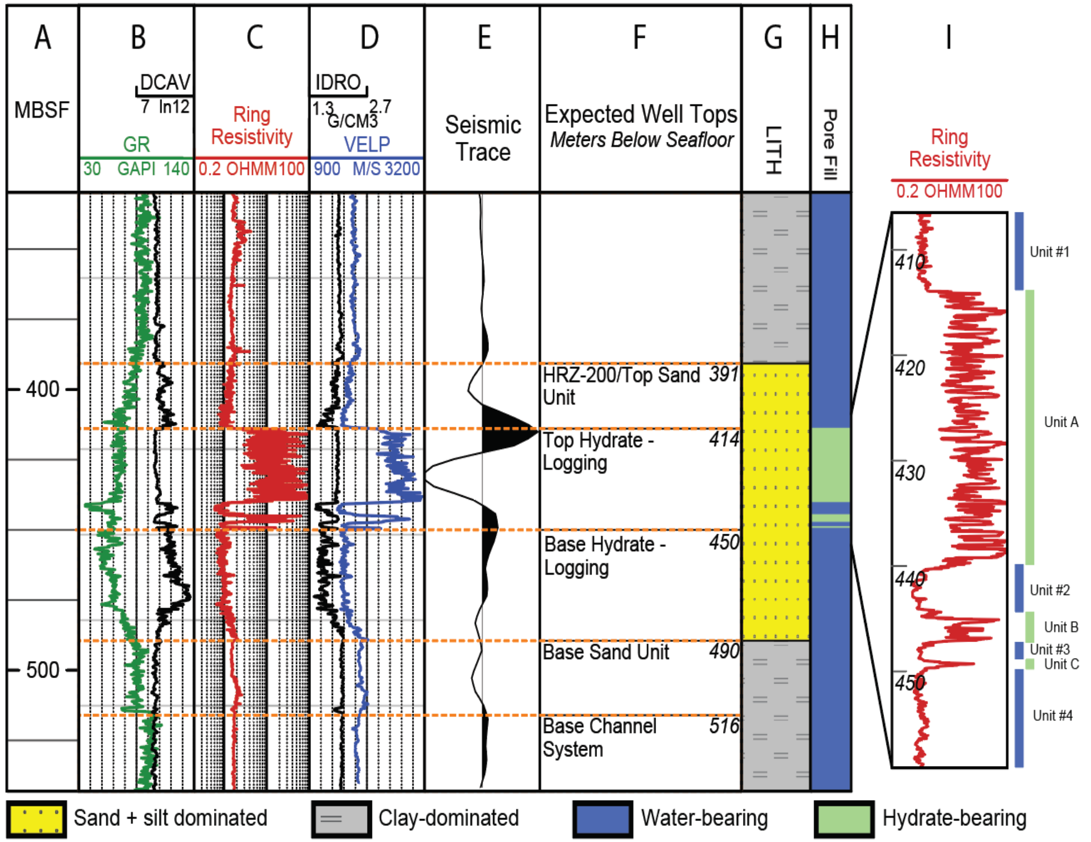


2. UT-GOM2-1 Green Canyon, Block 955

2017 'Marine Test'



Meazell et al., 2020, AAPG Bulletin 104, 9



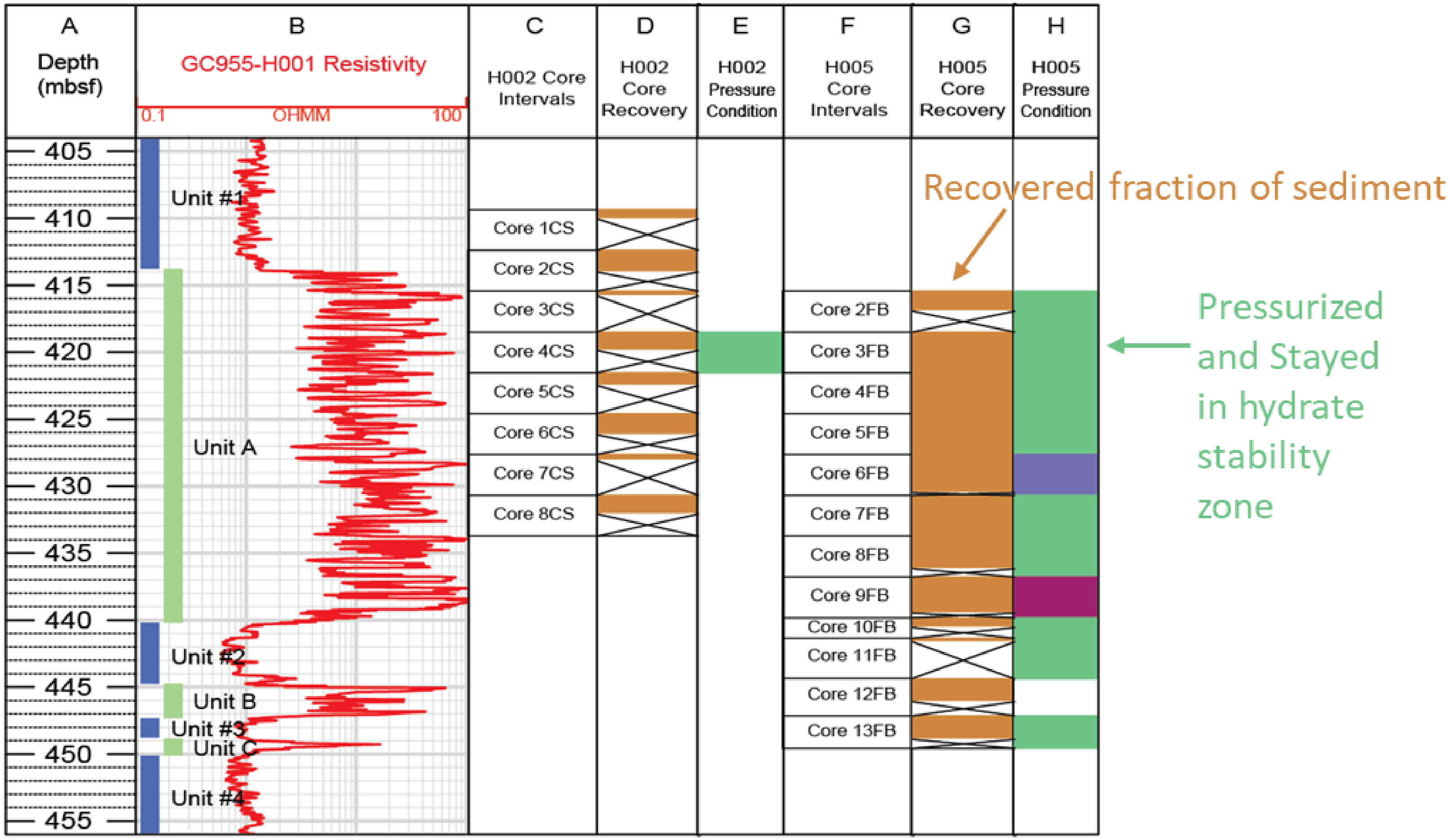
Flemings et al., 2020, AAPG Bulletin 104, 9

UT-GOM2-1 Technical Achievements and Scope

<u>Successes</u>

- 12 successful PCTB deployments
- 25.6 m of recovered pressure core
- ~21 m preserved and transported to UT Austin

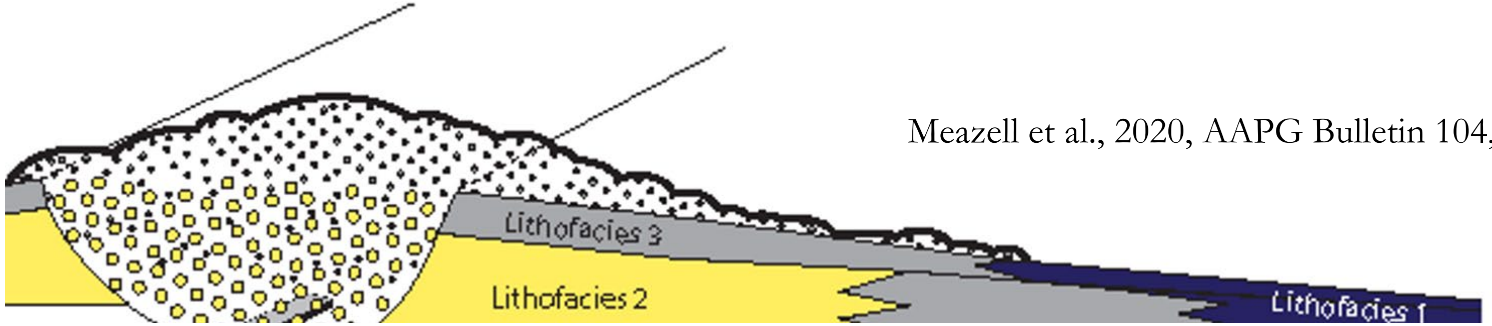
(Thomas et al., 2020, AAPG)



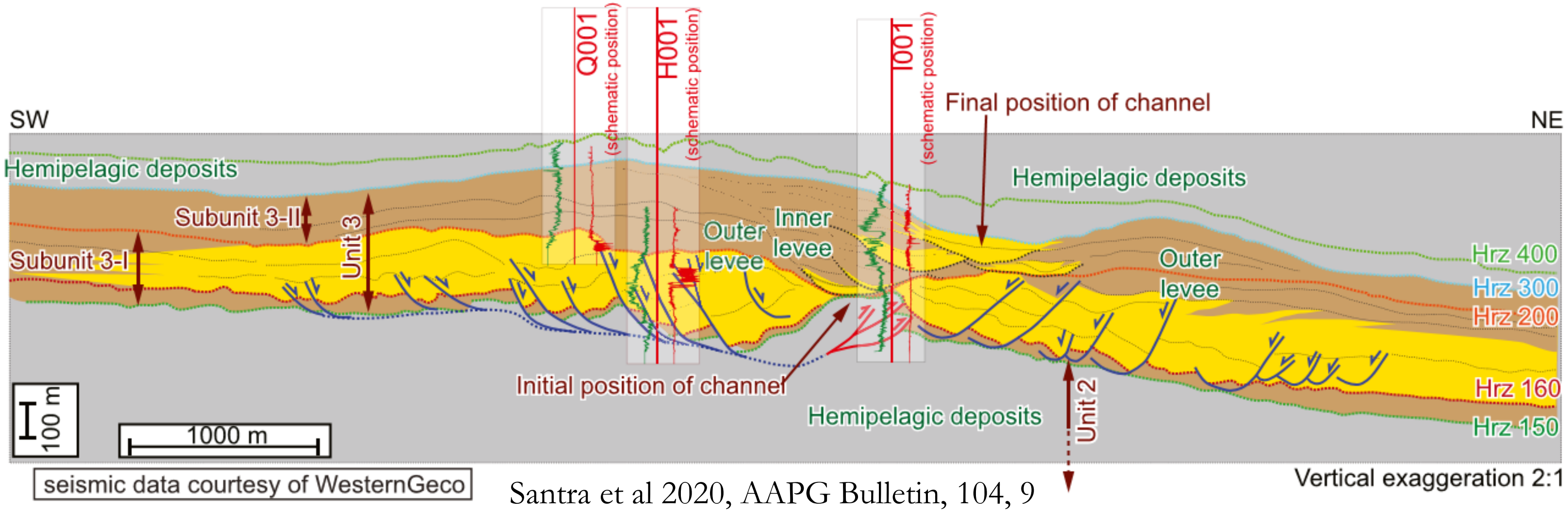
(Flemings et al., 2020, AAPG)

UT-GOM2-1 Science Achievements

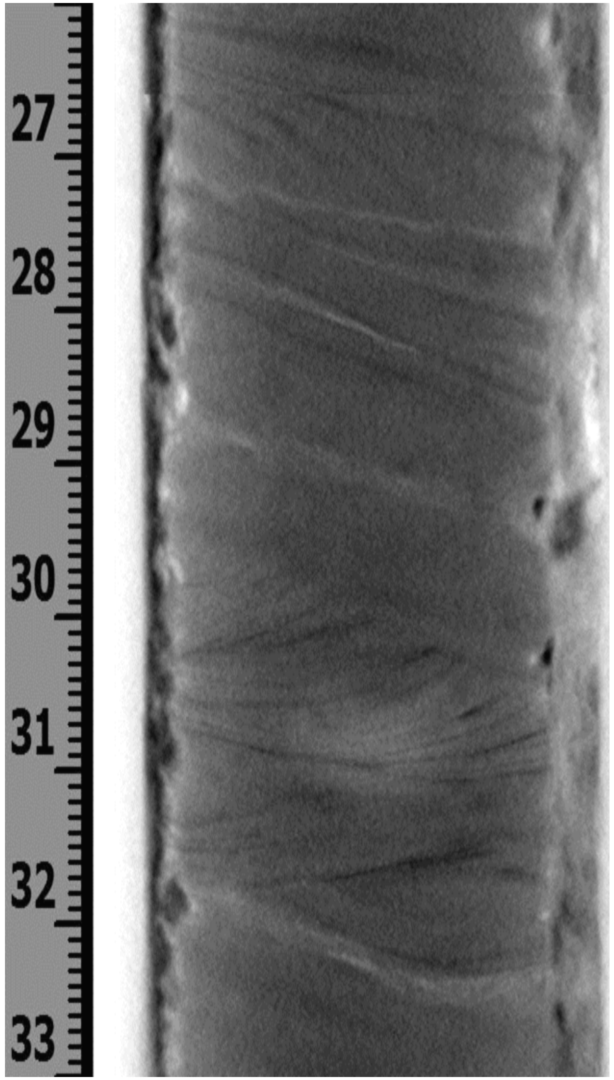
- Characterized the GC 955 hydrate reservoir
- Depositional model (Meazell 2020 et al. ; Santra et al., 2020)



Meazell et al., 2020, AAPG Bulletin 104,9



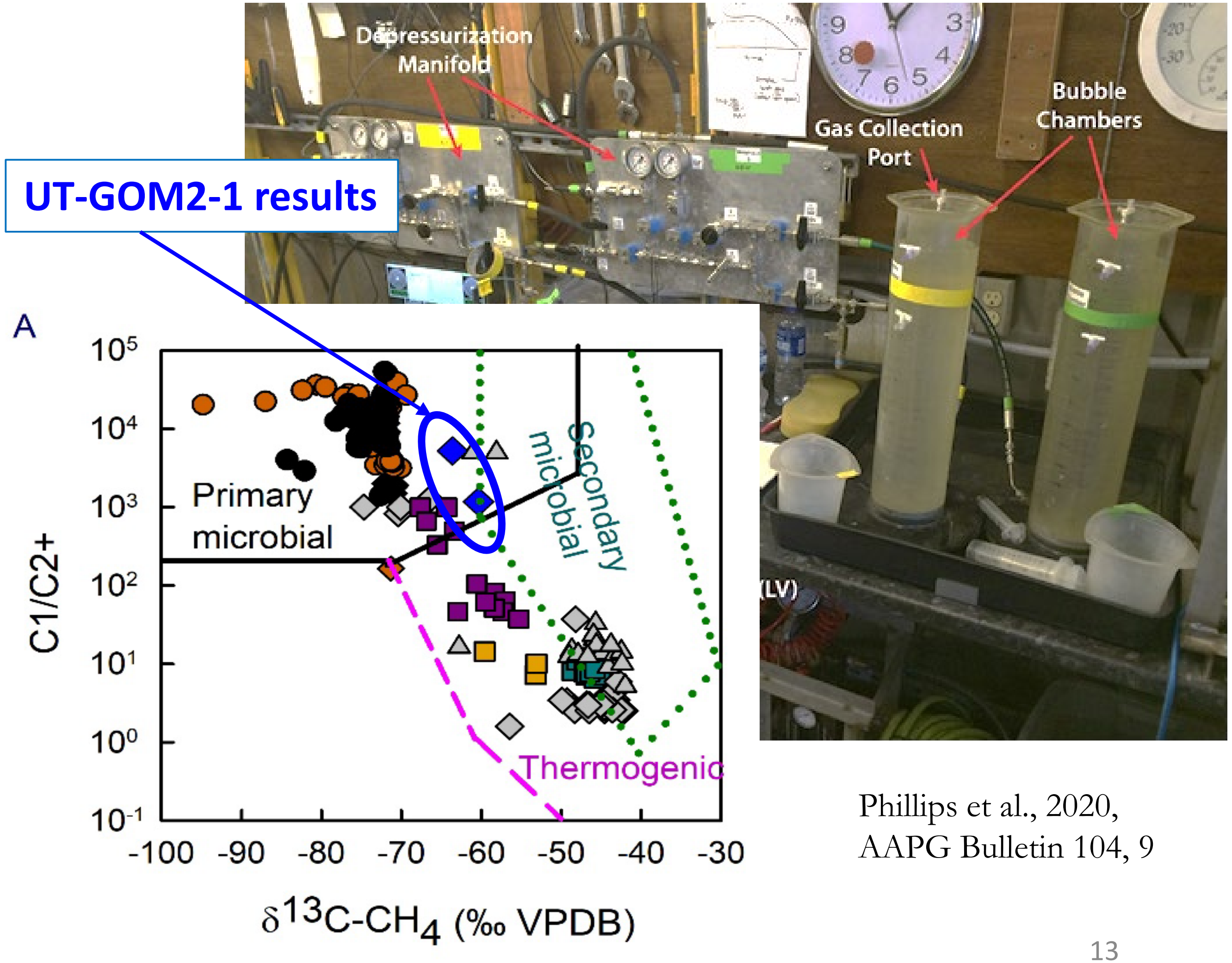
Santra et al 2020, AAPG Bulletin, 104, 9



UT-GOM2-1 Science Achievements

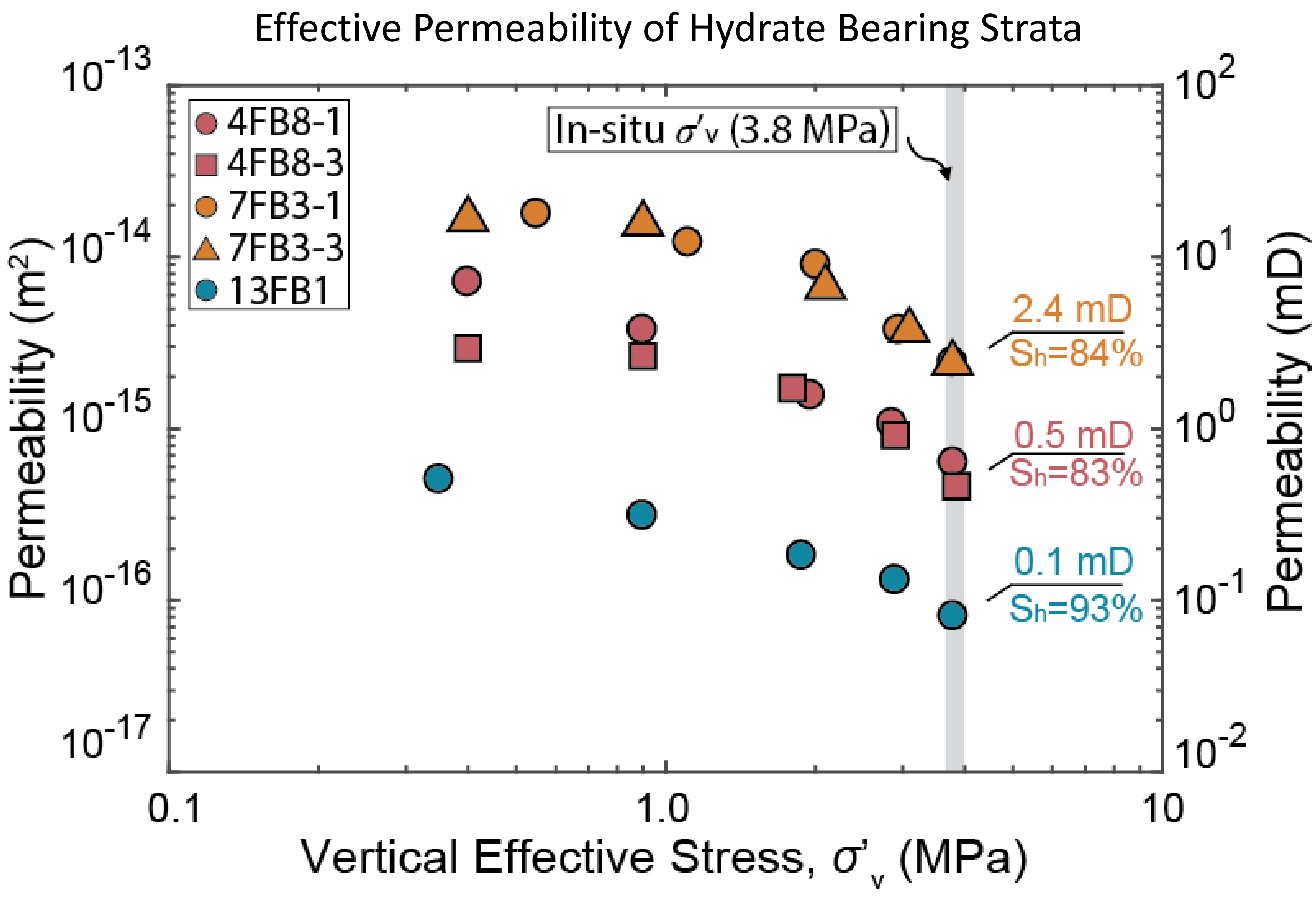
- Characterized Hydrate Concentration
    - 90% of sandy silt pore space is filled with hydrate
    - Water of seawater salinity

- Gas interpreted to be biogenic (microbial) in origin with possible trace thermogenic

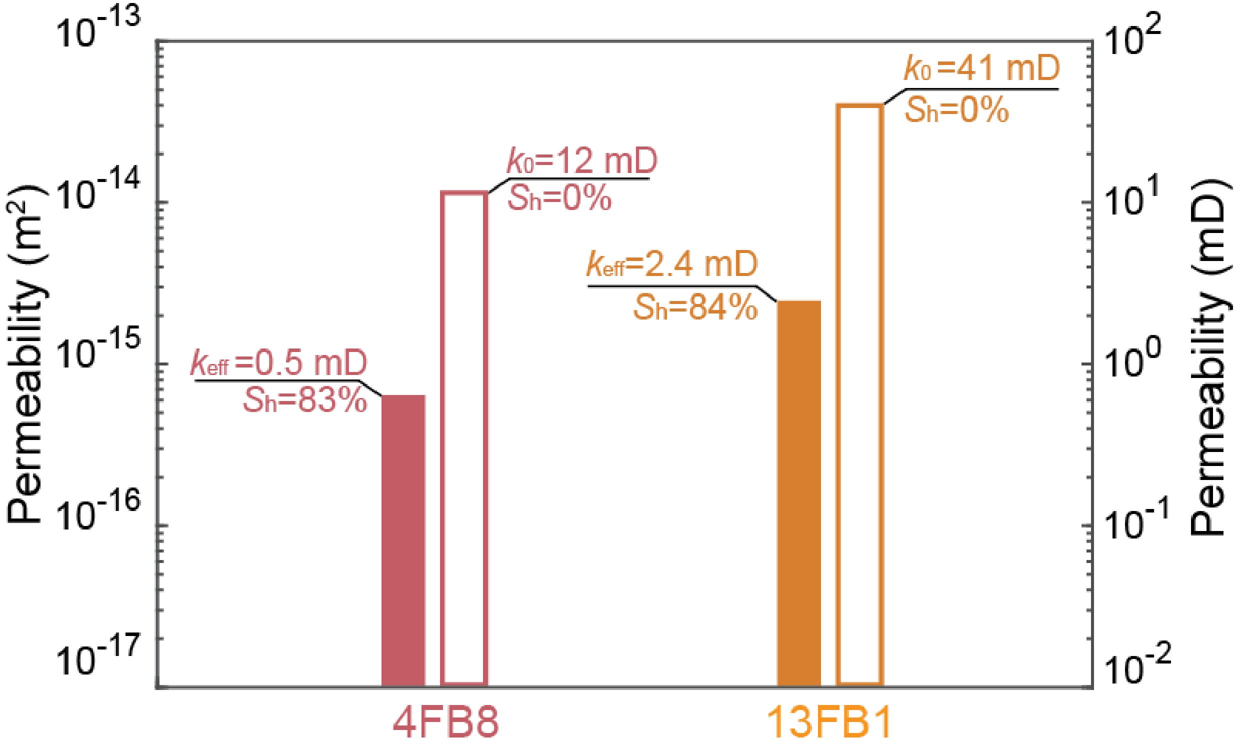


Phillips et al., 2020, AAPG Bulletin 104, 9

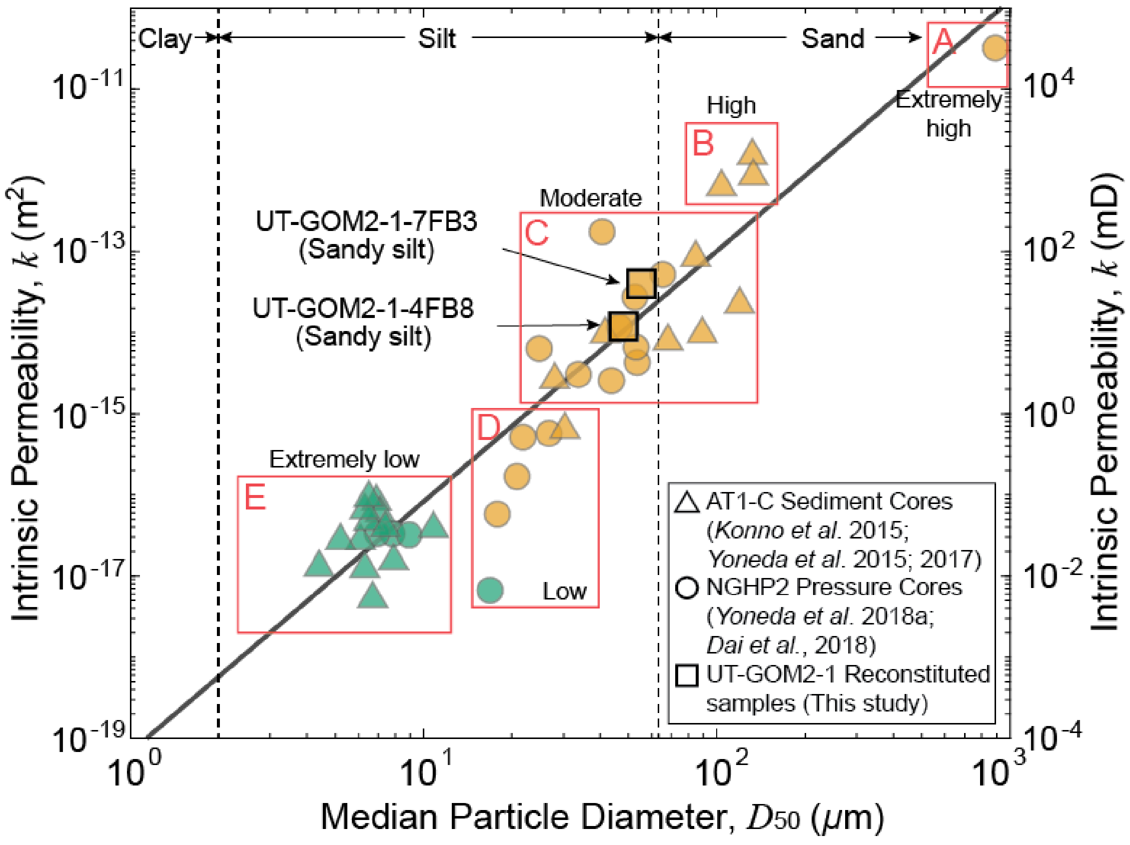
UT-GOM2-1 Science Achievements



UT-GOM2-1 Science Achievements



Intrinsic permeability is about 20-fold larger than its effective permeability at in-situ effective stress

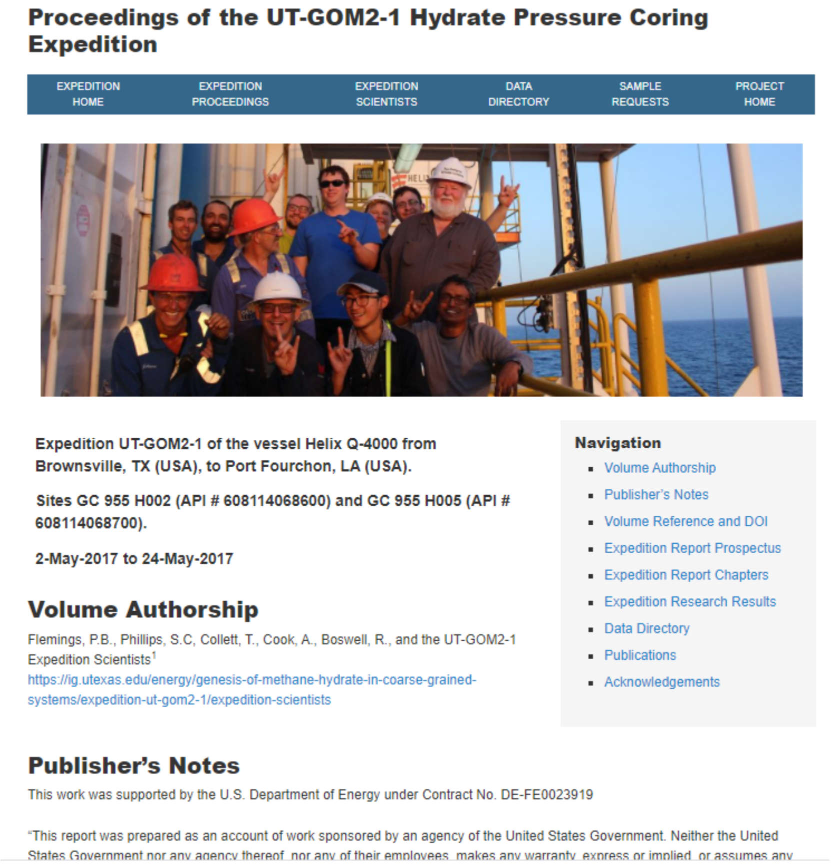


(Fang et al., 2020)

GC 955 Reservoir has 'Moderate' permeability relative to other hydrate reservoirs.

UT-GOM2-1 Proceedings

Find these results and more on our website, in OSTI, and in the AAPG Bulletin



Proceedings of the UT-GOM2-1 Hydrate Pressure Coring Expedition

EXPEDITION HOME | EXPEDITION PROCEEDINGS | EXPEDITION SCIENTISTS | DATA DIRECTORY | SAMPLE REQUESTS | PROJECT HOME

Expedition UT-GOM2-1 of the vessel Helix Q-4000 from Brownsville, TX (USA), to Port Fourchon, LA (USA).

Sites GC 955 H002 (API # 608114068600) and GC 955 H005 (API # 608114068700).

2-May-2017 to 24-May-2017

Navigation

- Volume Authorship
- Publisher's Notes
- Volume Reference and DOI
- Expedition Report Prospectus
- Expedition Report Chapters
- Expedition Research Results
- Data Directory
- Publications
- Acknowledgements

Volume Authorship

Flemings, P.B., Phillips, S.C, Collett, T., Cook, A., Boswell, R., and the UT-GOM2-1 Expedition Scientists[1]
https://ig.utexas.edu/energy/genesis-of-methane-hydrate-in-coarse-grained-systems/expedition-ut-gom2-1/expedition-scientists

Publisher's Notes

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Proceedings of the UT-GOM2-1 Hydrate Pressure Coring Expedition

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- Technical Report
- Data
- Software
- Patent
- more

AVAILABILITY
- Full Text / Resource Available
- Citation Only

PUBLICATION DATE
2017 2020

1. Data Report: High-Resolution Microscopy Images of Sediments from Green Canyon Block 955, Gulf of Mexico
Heber, Ryan ; Cook, Ann E ; Sheets, Julia ; ...
We took Leica microscopy images of sediment samples acquired at Holes H002 (4 samples) and H005 (1 sample) during the UT-GOM2-1 Expedition in Green Canyon Block 955, in the northern Gulf of Mexico. A total of 37 images were acquired. The images document a prevalence of spherical conchoidal minerals, cleavage planes typical of feldspar or mica, and black fragmented minerals which stand out from the surrounding matrix. Drilling mud intrusion is thought to contribute to a grey metallic matrix observed across multiple samples.
DOI: 10.2172/1648312 | Full Text Available

2. Data Report: X-Ray Diffraction of Sediments from Green Canyon Block 955, Gulf of Mexico
Heber, Ryan ; Cook, Ann E ; Sheets, Julia ; ...
We performed 18 X-ray diffraction (XRD) measurements on sediment samples acquired at Holes H002 (6 samples) and H005 (12 samples) during the UT-GOM2-1 Expedition in Green Canyon Block 955, in the northern Gulf of Mexico. Results indicate a predominance of quartz, with significant proportions of alkali feldspar and carbonate, and minor amounts of amphibole, micas, and clays.
DOI: 10.2172/1648308 | Full Text Available

3. UT-GOM2-1 Expedition Methods
Flemings, Peter B ; Phillips, Stephen C ; Collett, Timothy S ; ...
This chapter documents the procedures and methods employed by the UT-GOM2-1 Expedition on the Helix

UT-GOM2-1 on OSTI

AAPG Bulletin, Vol. 104 Number 9, Sept 2020

3. Pressure Coring/Core Technology Development

- PCTB Pressure Coring
- Pressure Core Preservation
- Pressure Core Analysis

PCTB Pressure Coring

- Very complex tool
- Tool issues have overlapping consequences
- Initial lack of lab testing equipment and methods made source identification difficult
- Still, we’ve made continuous improvements
- Very excited about the possibilities for UT-GOM2-2
    - Finally able to isolate and resolve individual problems

GOM2 PCTB Pressure Coring

SLC Lab/Bench Tests
- Tool tested in parts

Tool modifications:
- Improved ball valve speed
- Ball valve follower strengthened

Land Test 1
- 50% of runs sealed
- Poor core recovery

Tool modifications:
- Improved flow in upper tool, mud redirect

UT-GOM2-1
- 62% of runs sealed, but:
  - 9 sealed late
  - had to avoid top of reservoir
  - Only one demonstrated pressure boost

Tool modifications:
- Upper tool redesign
  - Single trigger mechanism
  - Shear pin update
  - New seals
  - Larger pressure boost reservoir

SLC Lab Upgrade
- 50' high pressure (5,000 psi) chamber with pneumatic actuator
- Allows complete tool assembly to be tested at field pressures

SLC Lab Tests
- 100% successful sealing at pressure in clean water, no late sealing
- 100% successful boost

Land Test 2
- Greatly improved core recovery vs Land Test 1
- Lower tool sealing sensitivity to grit clearly shown, only 14% of runs sealed

SLC Lab Tests
- Able to repeat grit failure in the lab!

SLC Lab Tests
- Latest tests 100% sealed in the presence of grit

Tool modifications:
- Lower tool ball valve redesign
  - Iterating on final solution

2015	2016	2017	2018	2019	2020

Phase 1 10/2014-09/2015	Phase 2 10/2015-01/2018	Phase 3 01/2018-09/2019	Phase 4 10/2019-09/2020

PETTIGREW ENGINEERING

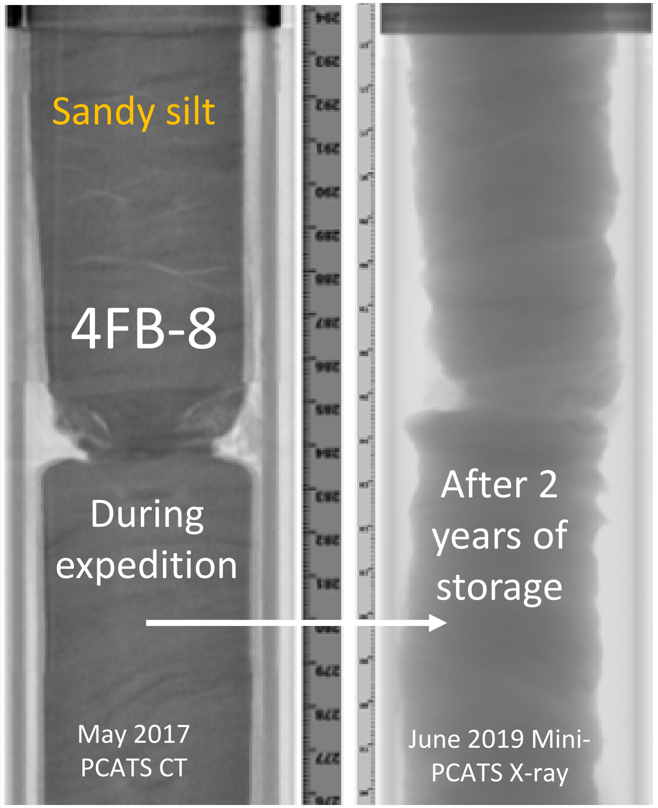
GEO TEK CORING

USGS

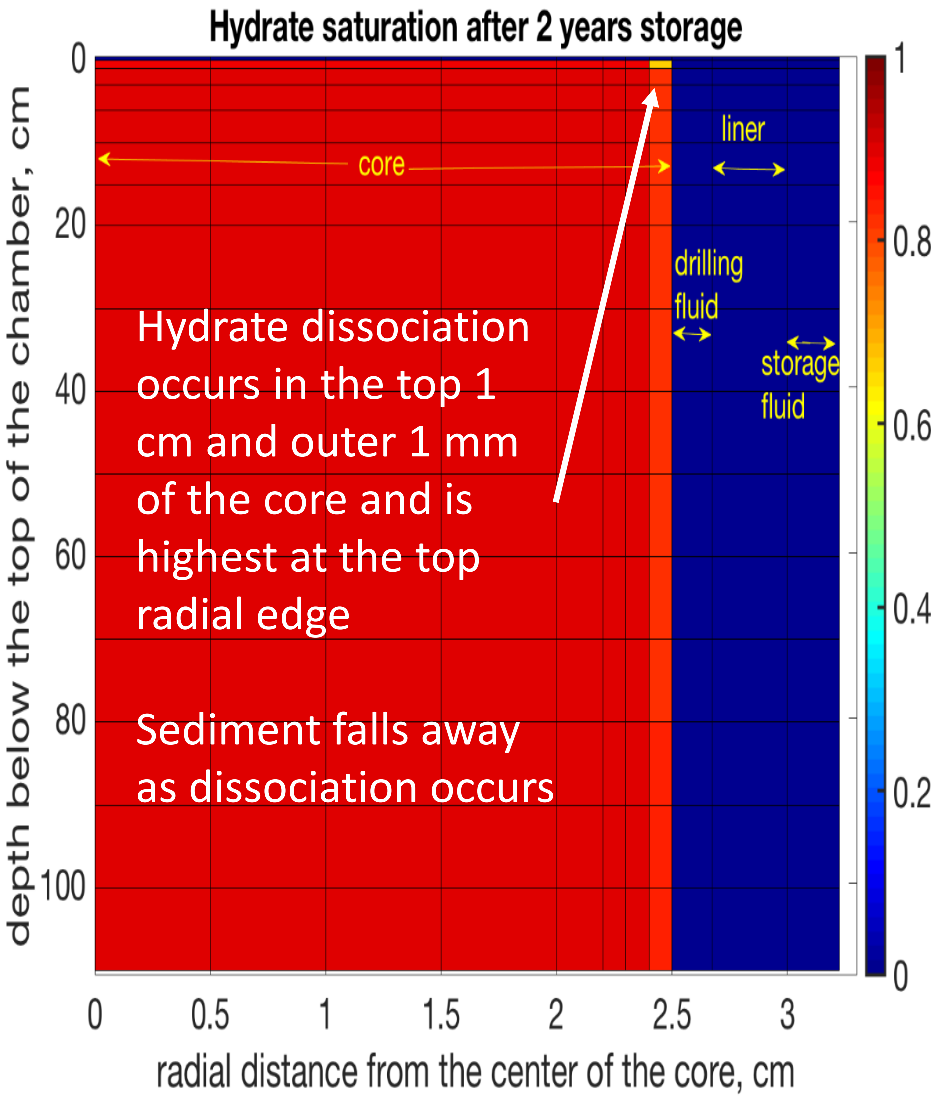
U.S. DEPARTMENT OF ENERGY

Core Preservation

- Hydrate-bearing pressure cores must be preserved for years for experimental programs.
- Significant core degradation is occurring in storage
- Degradation is roughly equal to the amount of methane that can be dissolved into storage fluid



2D radial model of Sandy silt PC stored with fresh water



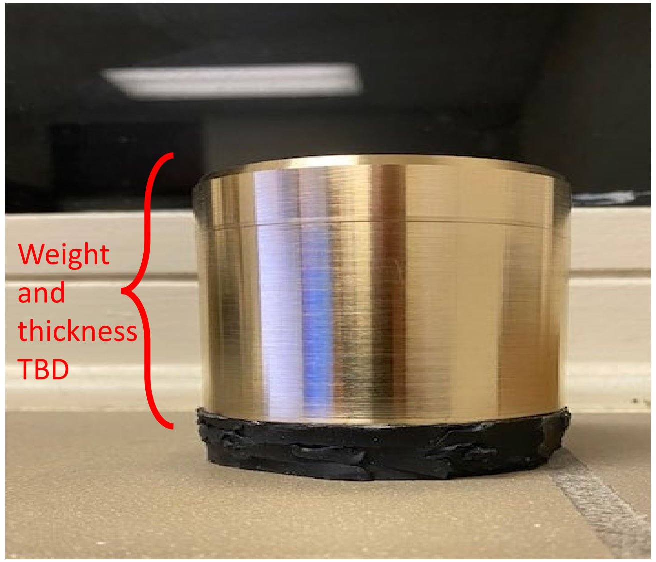
Core Preservation

Minimize volume of storage fluid

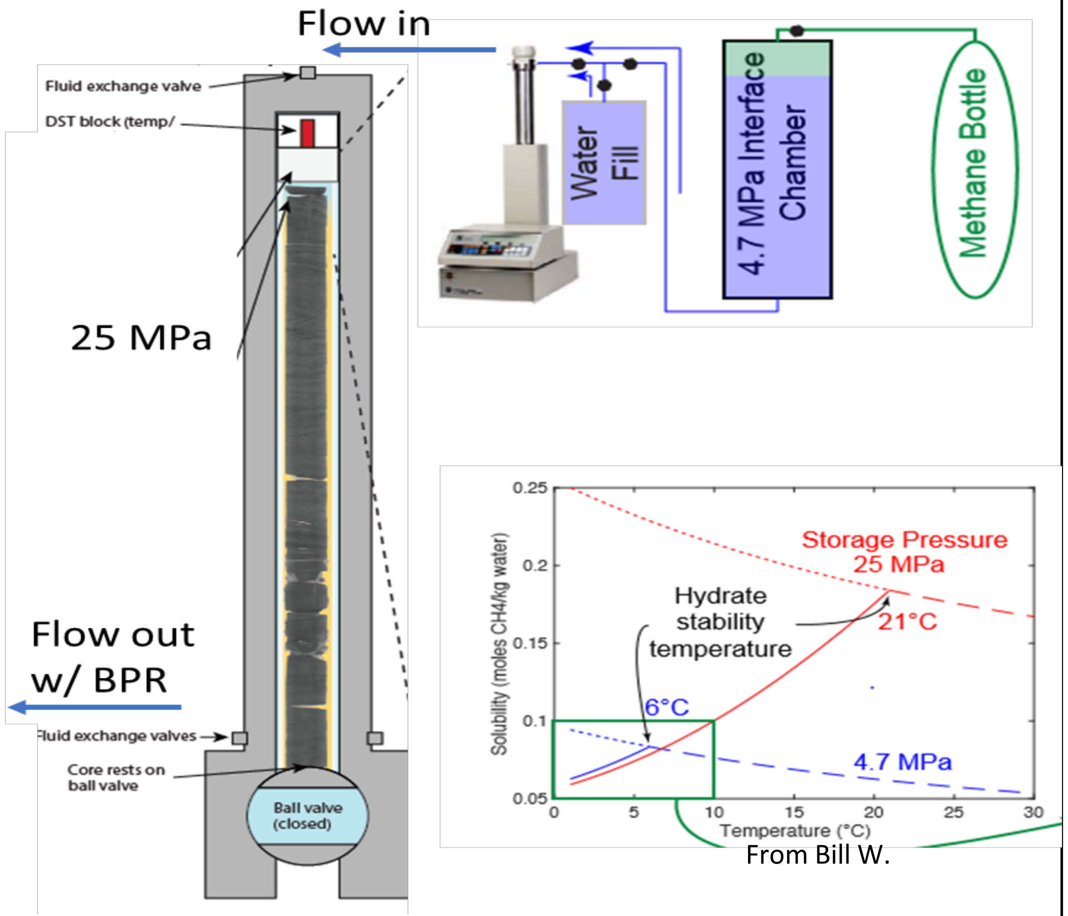
- Consolidate PCATS processing
- Eliminate use of core liner as a spacer
- Possibly reduce the inner dimeter of the storage chambers or add core chamber sleeves

Effectively seal core from storage fluid

- Add weighted rubber seal above the core liner
- Possibly spring loaded

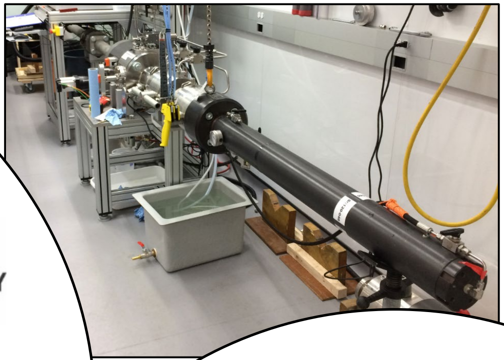


Charge storage fluid with methane without creating additional hydrate

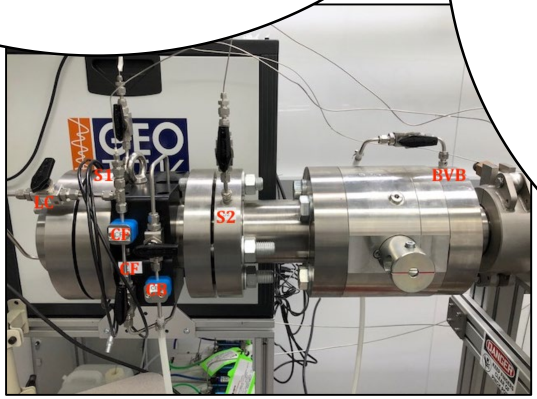


From Bill W.

Pressure Core Analysis

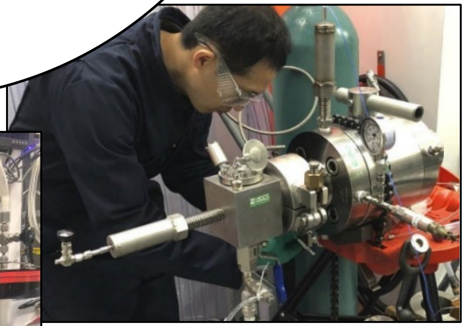


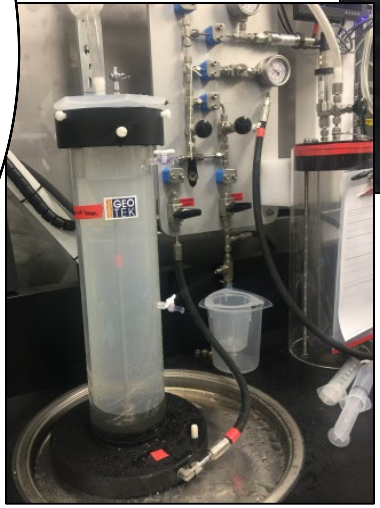
Petrophysics
- Improvements in measurement and understanding of intrinsic and effective permeability and strength



Gas Geochemistry
- Improvements in extraction methods and understanding of gas composition and fractionation

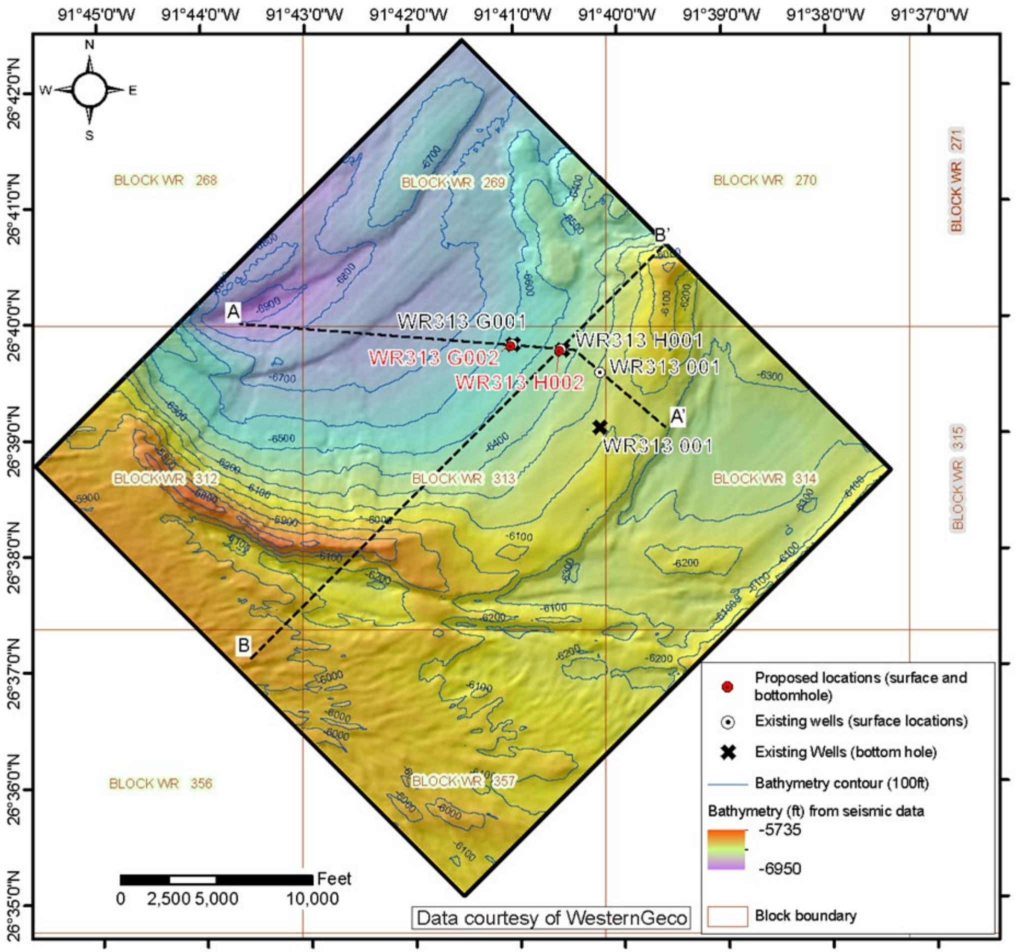
Microbiology
- Improvements in extraction, cultivation, and contamination

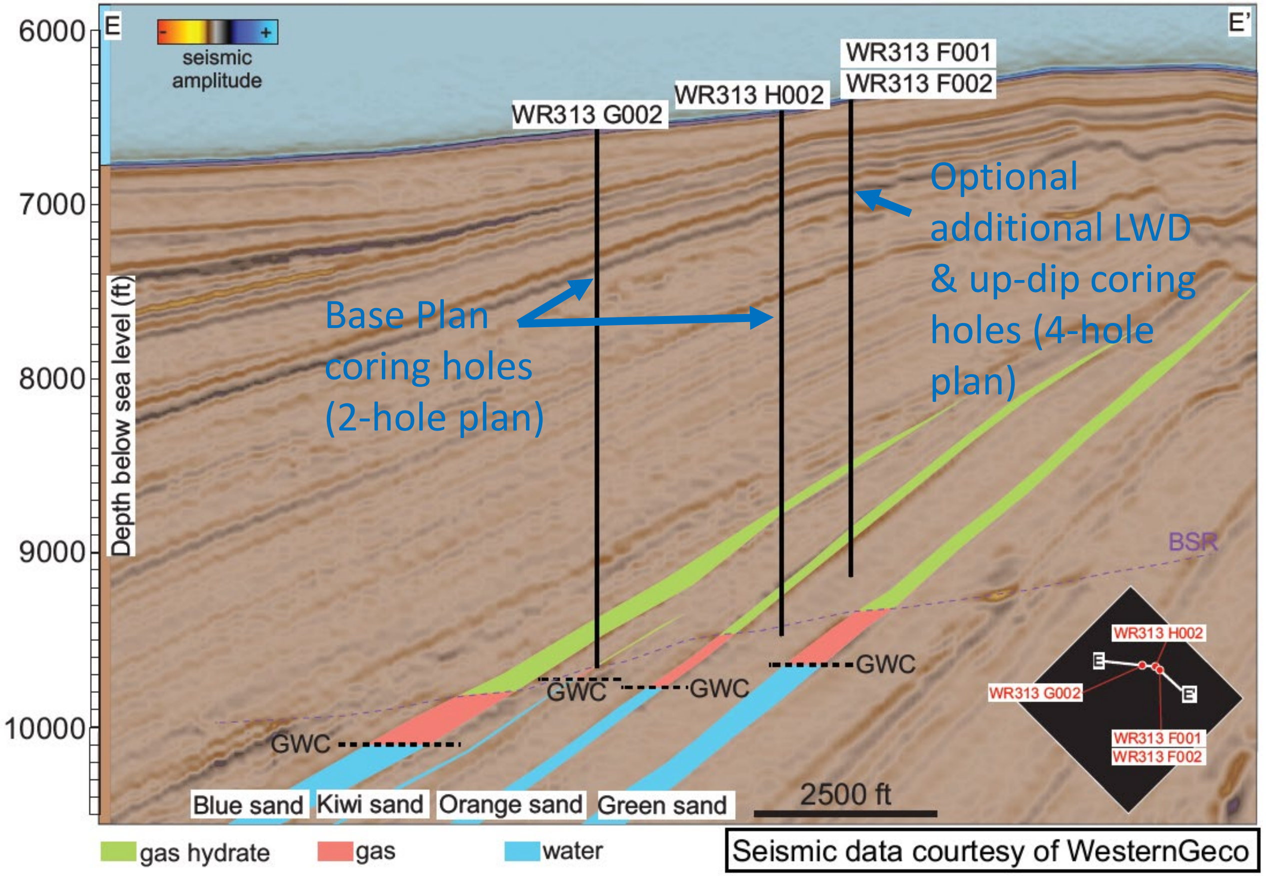




4. UT-GOM2-2 Walker Ridge, Block 313

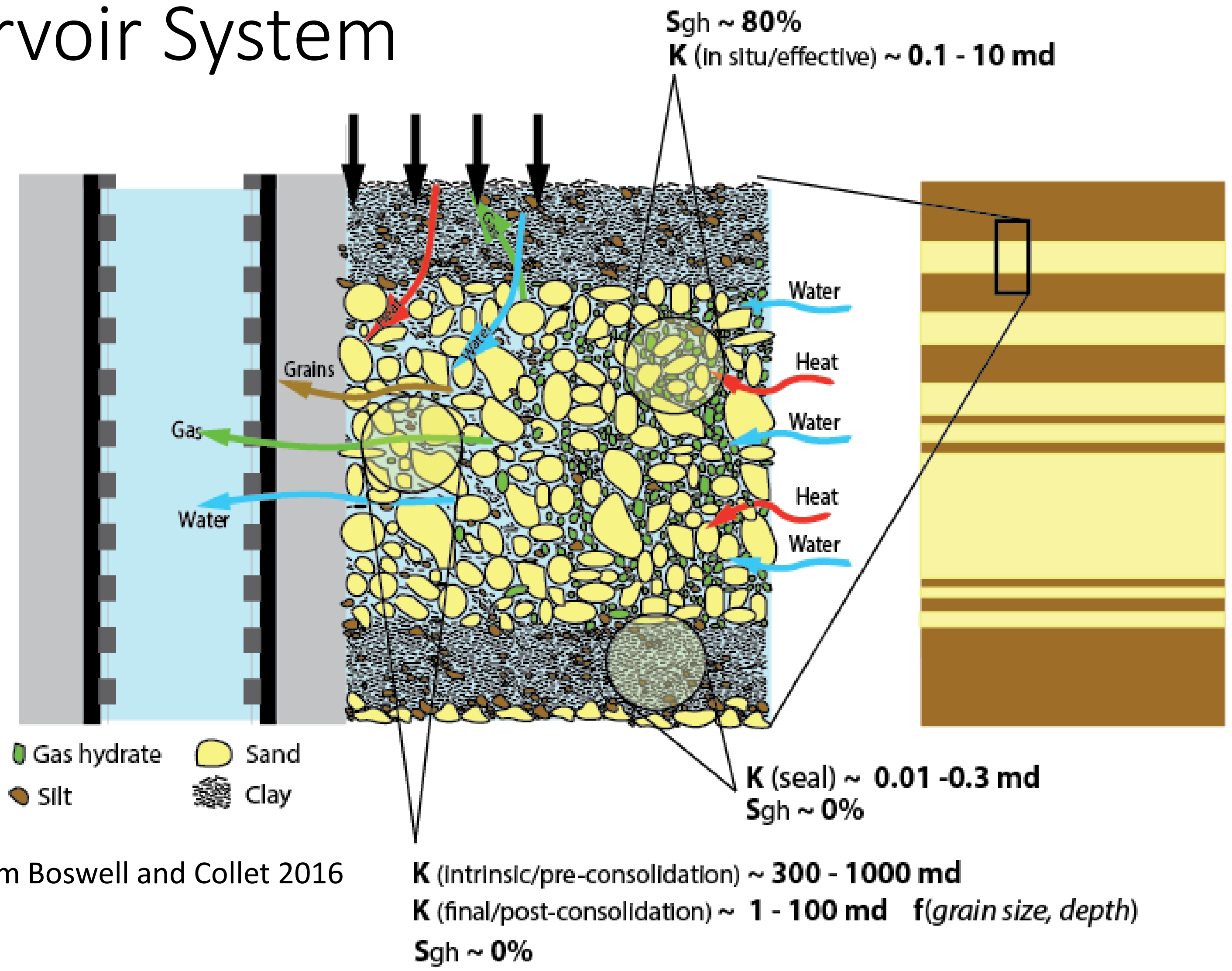
2-coring hole Scientific Expedition with option for additional LWD/coring holes





UT-GOM2-2 Science Objectives

Reservoir System



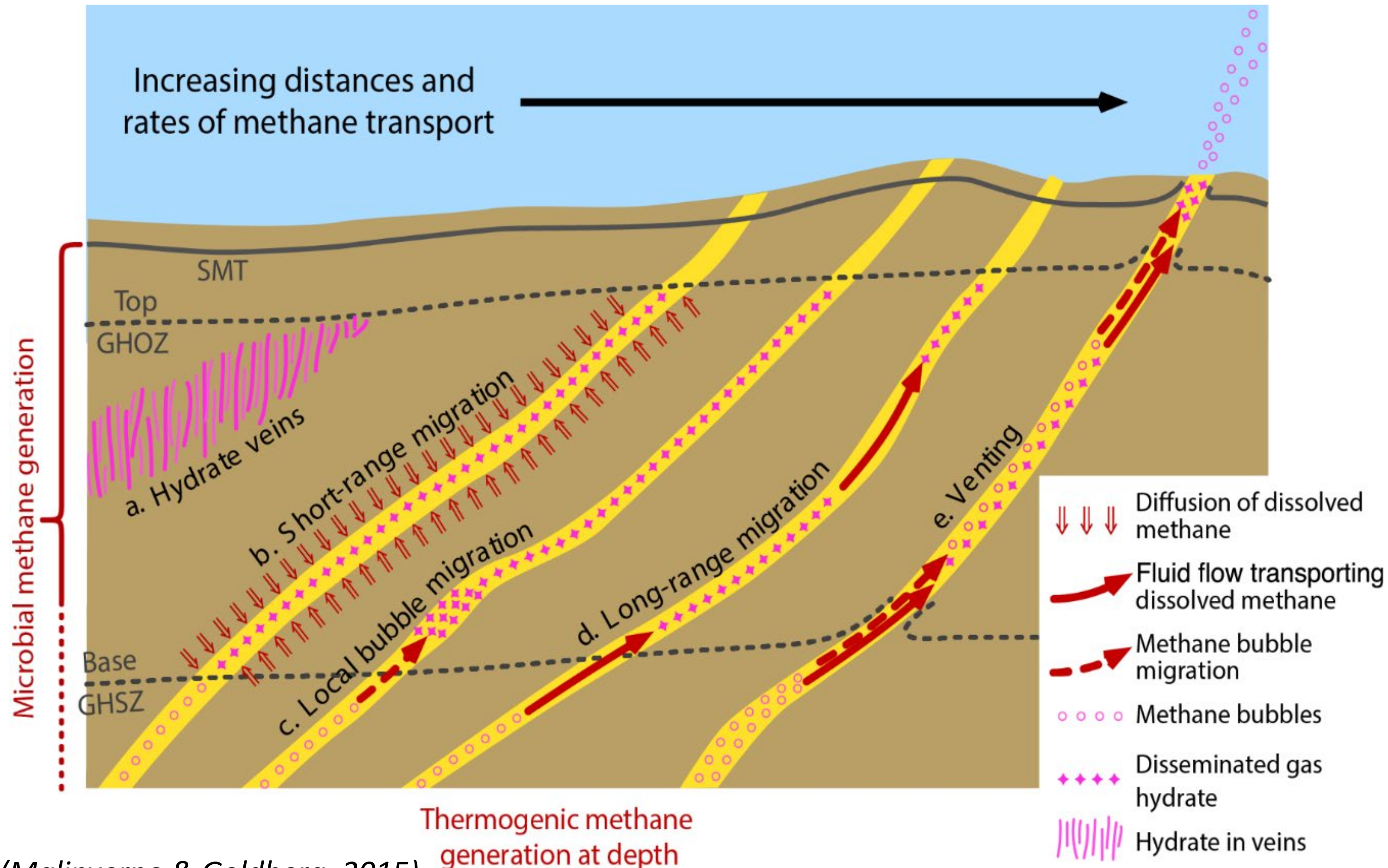
Modified from Boswell and Collet 2016

Steps:

- Obtain pressure core
- Determine hydrate concentration, gas composition, age, sediment texture, pore water chemistry
- Determine permeability, compression, capillary behavior, strength
- Elucidate reservoir production behavior to inform reservoir simulation

UT-GOM2-2 Science Objectives

Basin System



(Malinverno & Goldberg, 2015)

Steps:

- Collect sediment (some at in situ conditions), 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 the microbial factory works (shallow vs deep methane generation)
  - How are the products transported to the deposit
- Elucidate basin origin and evolution

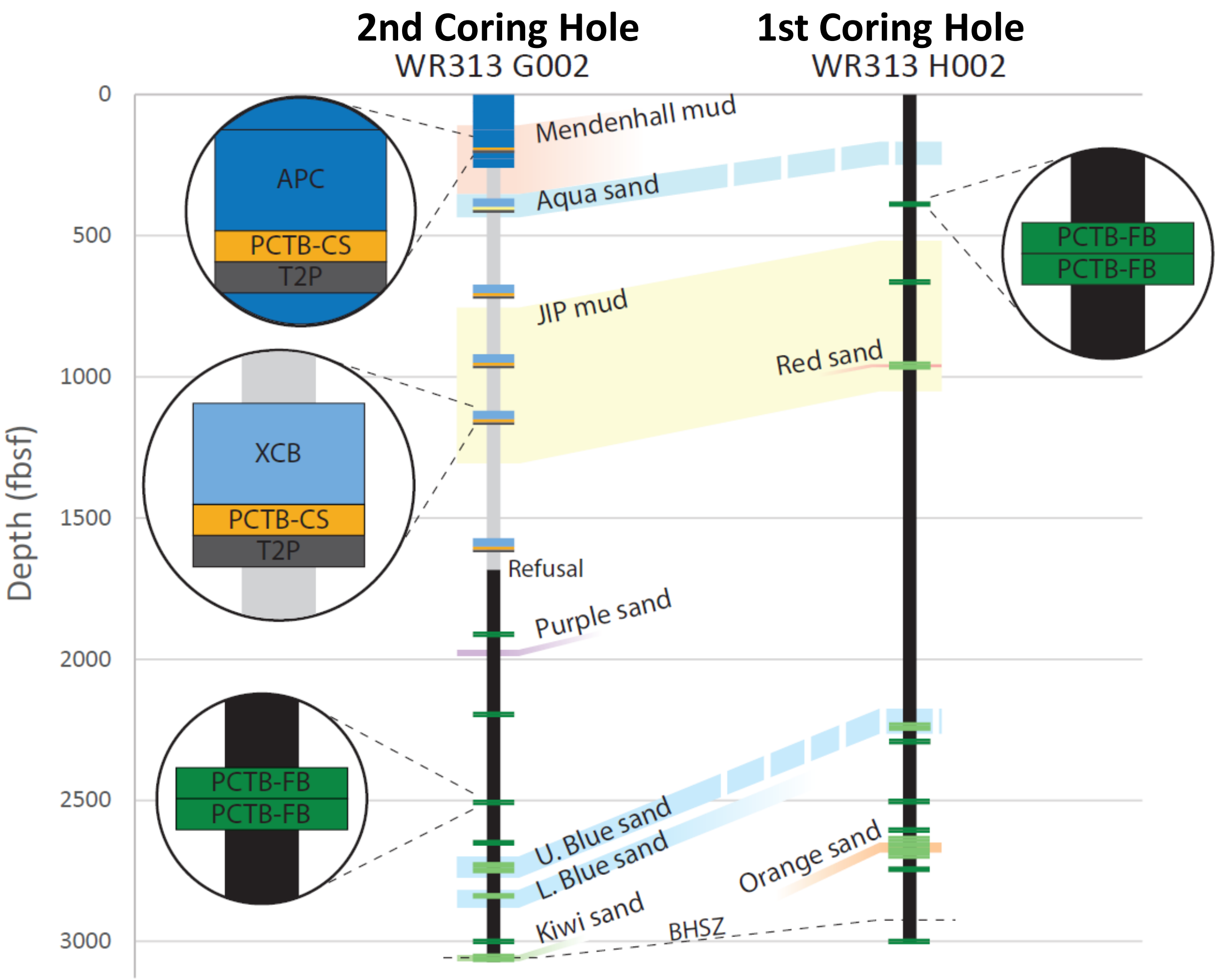
UT-GOM2-2 Science Objectives

6 Specific objectives all contribute to reservoir and basin systems understanding of WR313

1. Characterize the primary and secondary hydrate reservoirs and their bounding units (**Orange Sand**, and **Upper Blue Sand**, respectively).
2. Contrast hydrate reservoir properties at different structural levels within a dipping sand (**Upper Blue Sand 2-hole, Orange Sand with 4-hole option**)
3. Characterize dissolved methane concentration and gas molecular composition with depth
4. Measure in-situ temperature and pressure profile
5. High-resolution geochemical and sedimentary profiles
6. Reservoir characterization of other targets of interest

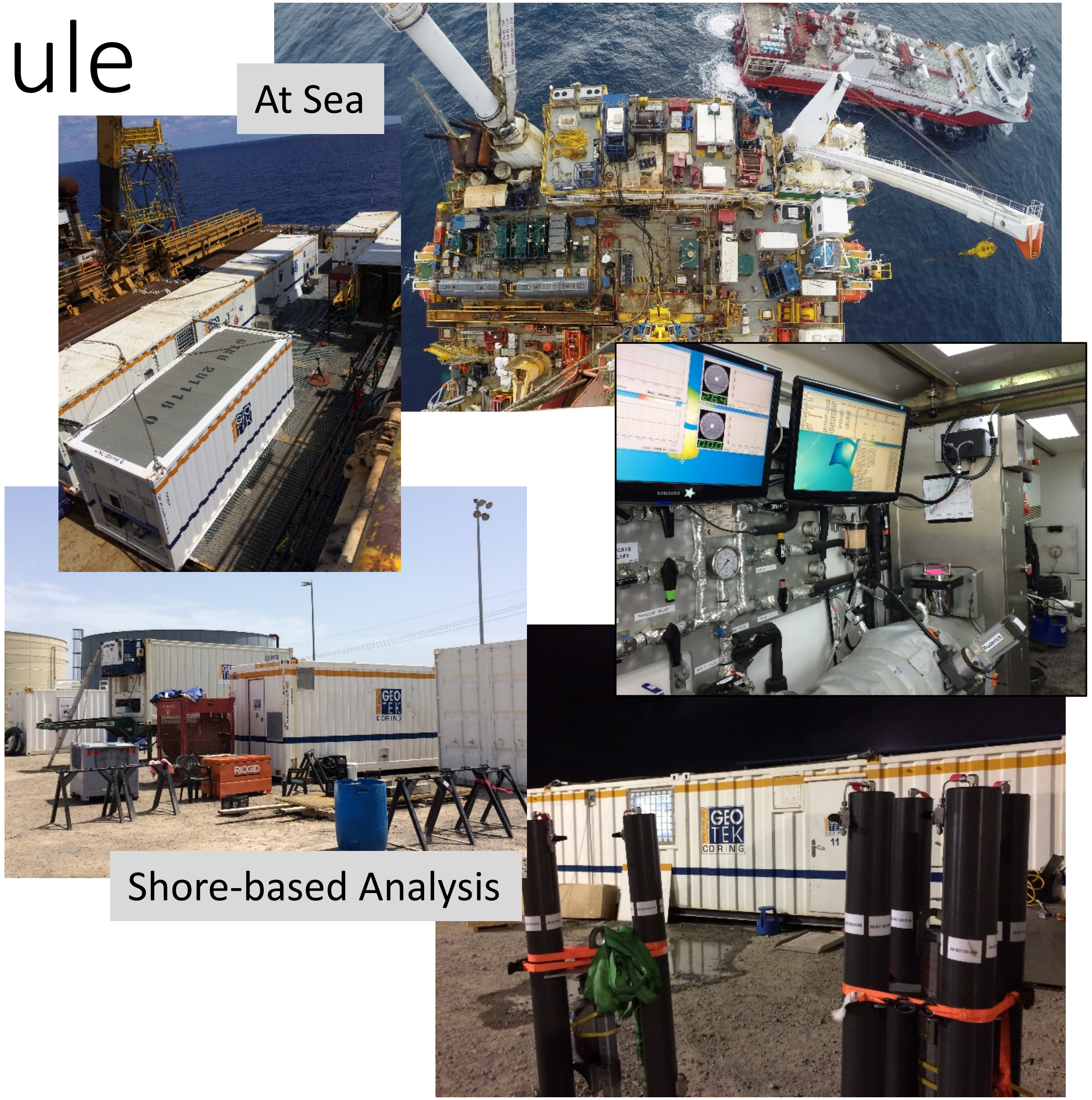
UT-GOM2-2 2-Hole Operations

- 53 Pressure coring runs
- 13 Conventional cores
- 100% Pressure coring in the 1st Hole to meet Objective #1: Characterize the **Orange sand**
- In situ temperature and pressure measurements
- Spot coring pairs ensure we obtain 1 clean core at each depth



UT-GOM2-2: 2-hole Schedule

- Target - Spring 2022
- ~78 day total program
  - 1 week period for staging at port of embarkation
  - 38.5 days at sea
    - 3.7 days mobilization
    - 31.8 days coring program
    - 3 days demobilization
  - 30 days dockside analysis program



UT-GOM2-2 Science Program

- On-board/Dockside
- Dockside only
- Shore-based Laboratory
- TBD Laboratory

Pressure Core

Pressure Core

- Gamma Density
- P-wave Velocity
- CT Imaging
- Hydrate Saturation
- PW Dissolved Methane
- Permeability
- Compressive Strength
- Micro-Raman
- Micro-CT (NETL)
- PCCT (USGS)
- PNAT (AIST)
- Microbiology

Gas Geochemistry

Collected gas samples

- Hydrocarbons (C1-C6)
- CO_2
- Hydrocarbons (C1-C6)
- Noble Gases: ^{4}He, ^{20}Ne, ^{36}Ar, Kr, and Xe
- Isotopes: $\delta^{13}C\text{-}CH_4$, $\delta D\text{-}CH_4$, $\delta^{13}C\text{-}CO_2$
- Isotopes: $\delta^{13}C\text{-}C_2H$
- Clumped Isotopes: $^{13}CH_3D$, $^{12}CH_2D_2$

Conventional & Depressurized Core

Conventional Core

- Thermal Imaging
- Void & Headspace Gas
- Thermal Conductivity
- Sediment Shear
- Resistivity
- Gamma Density
- P-wave Velocity
- Natural gamma
- Magnetic susceptibility
- CT Imaging
- MAD
- Microbiology

Split Core

Archival Half

- Magnetic Susceptibility
- High Def Photography
- X-ray Fluorescence
- Color Spectrophotometry

Pore Water Geochemistry

Pore Water section

- Salinity
- Alkalinity and pH
- DIC and $\delta^{13}C$-DIC
- DOC
- Chlorinity
- SO_4, Br, F
- Ca, Mg, Na, K
- Li, B, Cs, Rb, Ba, Sr, $^{87}Sr/^{86}Sr$
- Si, NH_4, dissolved sulfide, PO_4
- Trace Metals
- $\delta^{18}O$, δD of pore water
- VFAs & isotopes
- $^{34}S\text{-}H_2S$
- $\delta^{7}Li$
- $\delta^{37}Cl$

Sediment Properties

Working Half

- Smear Slide
- Course Fraction Microscopy
- Biostratigraphy: Primary
- Sediment Shear
- MAD: wet and dry weights
- CHNS/TOC
- Isotopic Analysis
- Rock Magnetism
- Grain Size: Laser Particle
- Carbon Nodules, if present
- Sulfide nodules, if present
- XRD including clay details
- Grain Size: Hydrometer
- MAD: Grain Density
- Biostratigraphy: Secondary

60+ analyses integrated to meet the 6 Science Objectives

UT-GOM2-2 Science Program Logistics

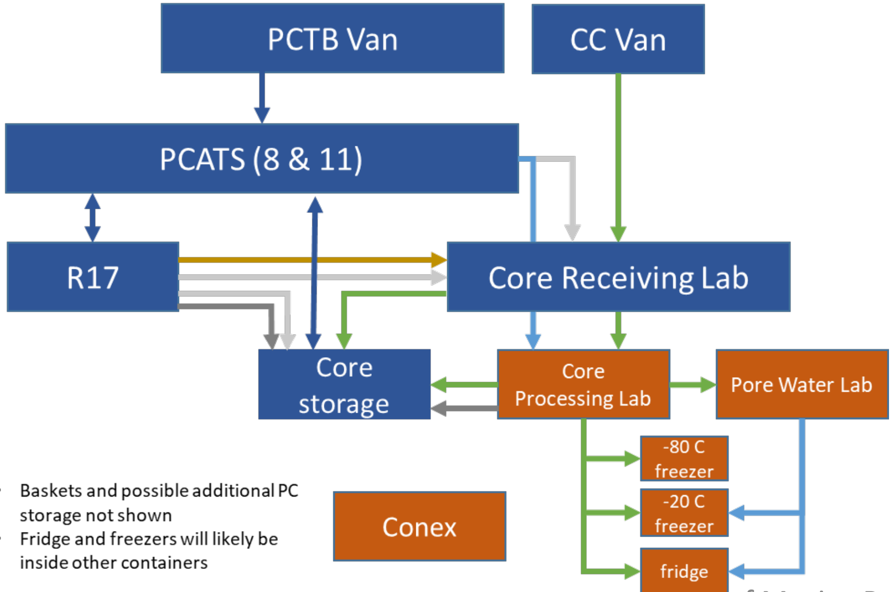
At Sea

On-board containers and sample movement

Complex movement of Equipment, People, Samples, and Data

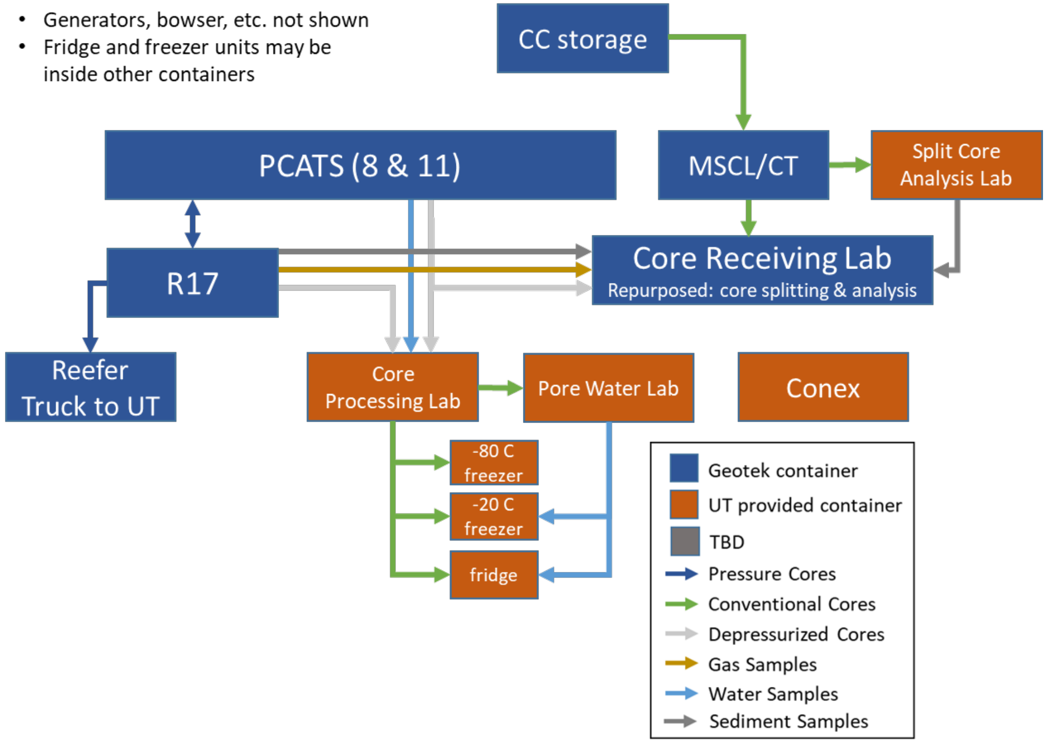
Shore-based Analysis

Dockside containers and sample movement



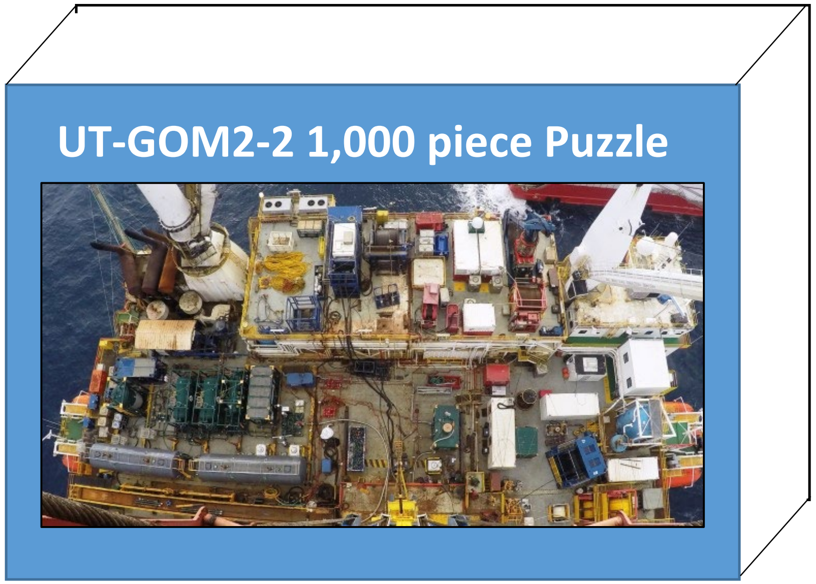
- Baskets and possible additional PC storage not shown
- Fridge and freezers will likely be inside other containers

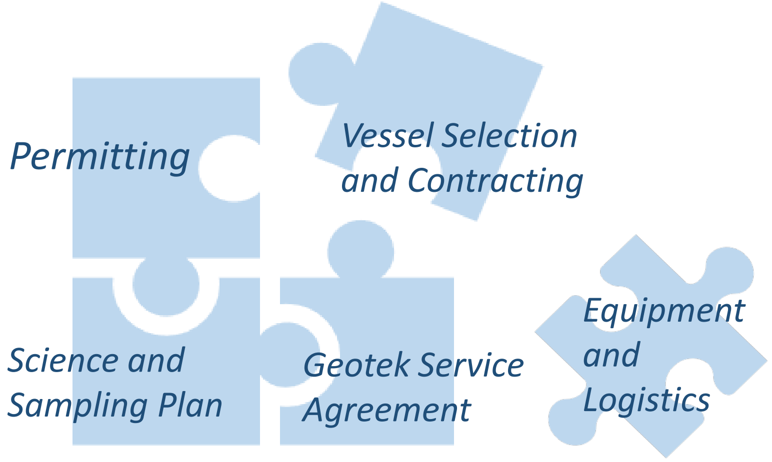
- Generators, bowser, etc. not shown
- Fridge and freezer units may be inside other containers



What are we doing today

- Working on initial permit submission
  - BOEM Exploration Plan
  - BOEM Right of Use & Easement (RUE)
- Completing upgrades and testing of PCTB & T2P
- Resolving the finer elements of the Science and Operational Plans
  - Personnel (who, when, and where)
  - Equipment and Supply Lists
  - Mobilization/Demobilization Port-of-Call Plans
  - Detailed Sampling Protocols





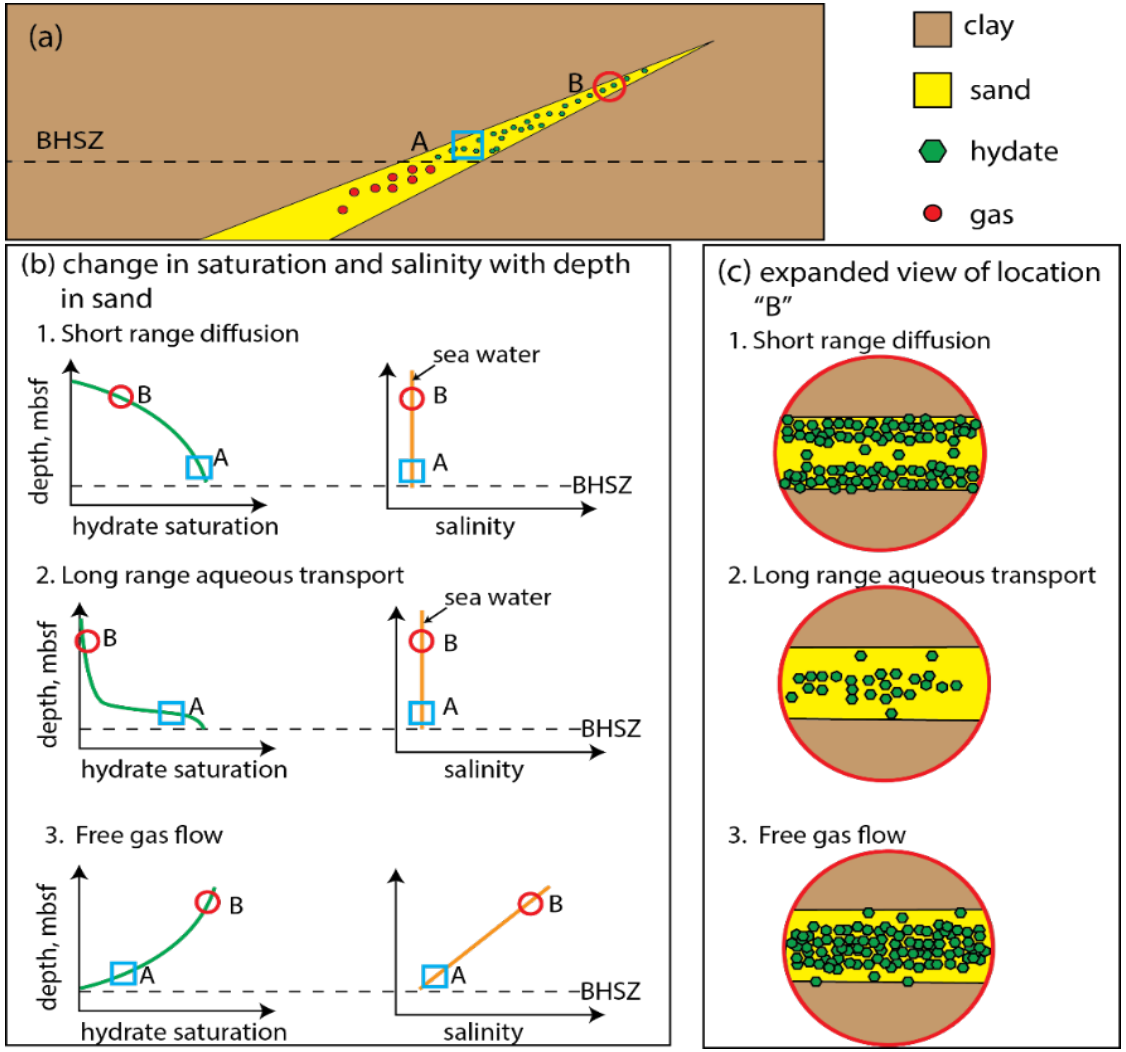
4 Well Program

- GOM2 Field Test envisioned with more science
- Contribution of resources from IODP was lost
- To meet budget significant science was cut and a 2 well program developed.
- We have maintained the ability to bring back a portion of what was lost as described in our 4-hole plan
- This is the exploration and coring of the up-dip **Orange Sand**
- Far cheaper to accomplish once you are out there, than come back another time.

Characterizing a dipping sand

- Original idea was to test hydrate formation models by characterizing differences in saturation and salinity along dip elevation.

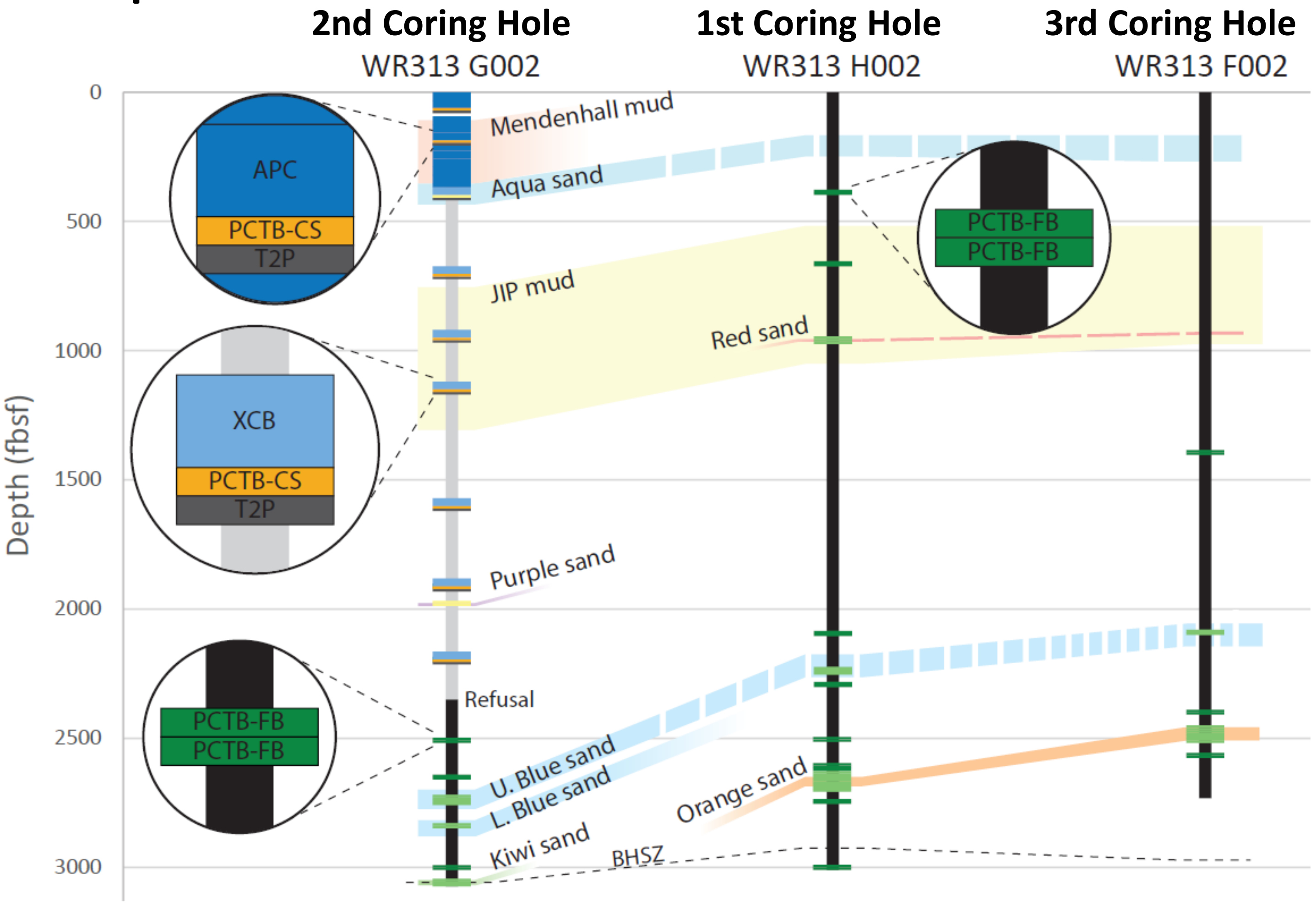
1. Orange sand across 01B and 02A is ideal – strong evidence of connectivity
2. Upper Blue Sand across 03B and 01B has uncertain connectivity



UT-GOM2-2 4-hole Operations

Option to add two additional holes:

- LWD F001
- 66 Pressure coring runs
- 13 Conventional cores
- 100% Pressure coring in the 1st and 3rd Coring Hole to meet Objectives #1 and #2
- In situ temperature and pressure measurements
- Spot coring pairs ensure we obtain 1 clean core at each depth



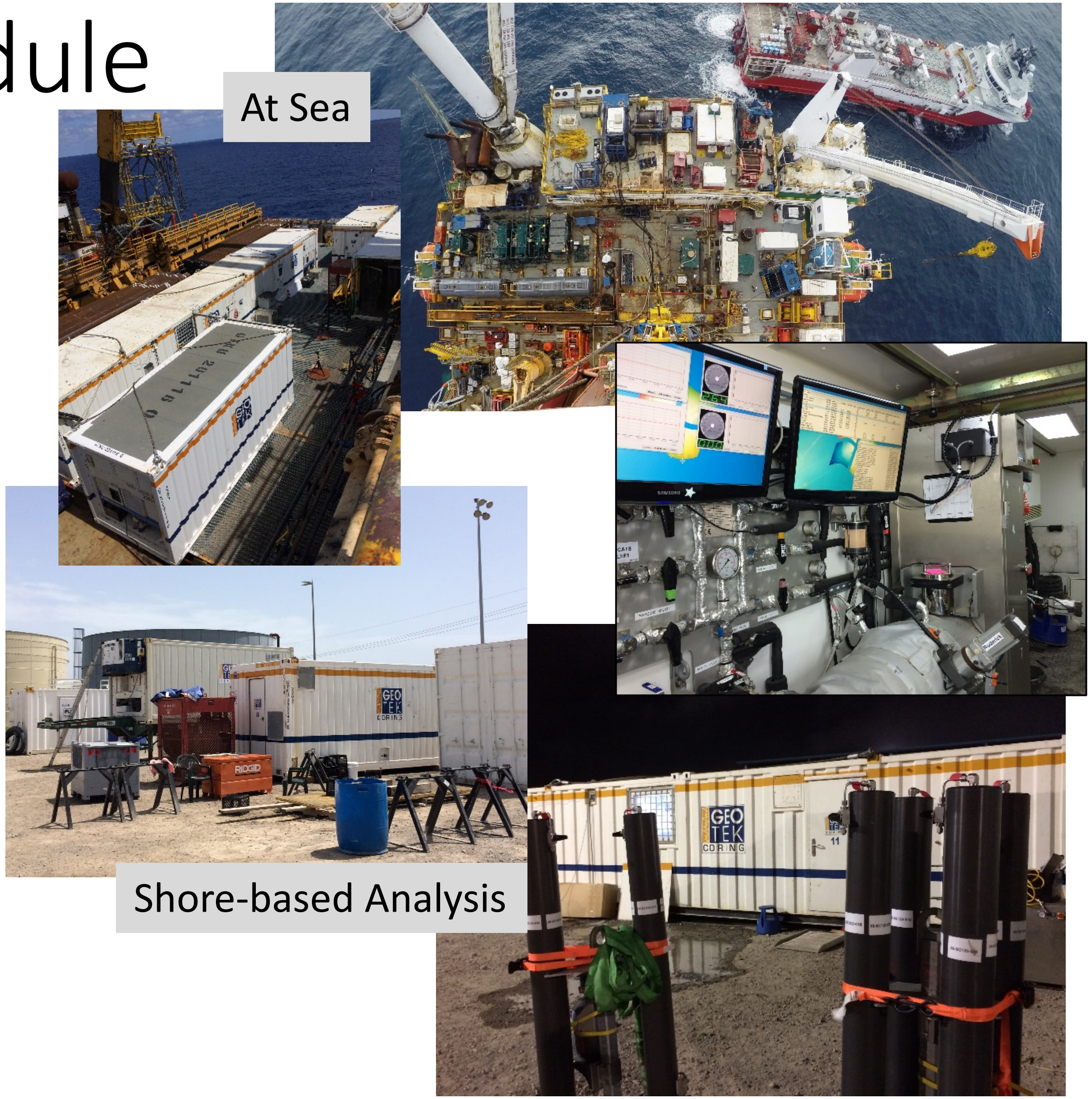
Including allowance cores

Additional science with the 4-hole Plan

- Pressure core characterization of clean-thick-dipping-continuous reservoir
  - Up-dip, down-dip comparison of seal properties, inter-bedding, grain size distribution, intrinsic permeability, etc.
  - Document lateral extent of Orange sand, confirms seismic predictions of hydrate saturation
  - Inform conceptual and numerical models of hydrate formation in dipping reservoirs
- Borehole characterization using Provisional Plus Logging-while-Drilling (LWD)
  - NMR provides information on permeability, porosity, pore size, hydrate saturation, hydrocarbon species; measurements that no other tool can provide
  - NMR distributions can be compared to bench-top pulse-NMR Pressure Core Measurements from AIST
  - Shear wave (SonicScope) used to understand geomechanically properties of hydrate, the habit of hydrate in the pore and differentiate between gas and gas hydrate. (Better shear waver vs JIP)
  - Borehole Resistivity Imaging (MicroScope) defines bedding orientation, fractures, faults and in situ stress directions. (Improve res over JIP, vertical resolution to 1 cm)

UT-GOM2-2: 4-hole Schedule

- +16 rig days LWD & coring
- +0 extra days mobilization/demobilization
- +0 extra days dockside analysis program



UT-GOM2-2 Options

2-hole Program

- **Science Achievements**:
  1. Characterize Orange sand at H002
  2. Limited characterization of hydrate reservoir at different thermodynamic states *(Blue sand at H002 & G002)*
  3. Limited characterization of diss. CH4 concentration and depth profile
  4. Measure thermal gradient at G002
  5. Limited high-resolution geochemical/sedimentary profiles
  6. Characterize other targets of interest (Red sand, etc.)
- **Duration**: 34 days

4-hole Addendum

- **Science Achievements**:
  1. LWD Provisional Plus, enhanced NMR, shear wave, and resistivity logging
  2. Pressure core characterize of Orange sand at different thermodynamic states *(H002 and F002)*
- **Duration**: +16 days

➢ *~50% of 2-hole duration*
➢ *~34% of 2-hole cost*

Challenges Ahead

- Vessel Contracting
- PCTB Land Test
- Complete permitting
- Execute Program
- Perform shore based science

Key Accomplishments

- Successful Field Execution: GOM2-1
- Linked 7 universities, DOE, BOEM, USGS
- Viable, and improving, pressure coring technology
- Fundamental contributions in characterization, laboratory analysis, and modeling
- Dedicated volume summarizing our findings at GC 955
- International research collaboration on analyses of pressure core samples

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END OF PRESENTATION
Thank you

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