Deepwater Methane Hydrate Characterization and Scientific Assessment

DE-FE0023919

P. Flemings and the GOM2 Team

The University of Texas at Austin

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

U.S. Department of Energy

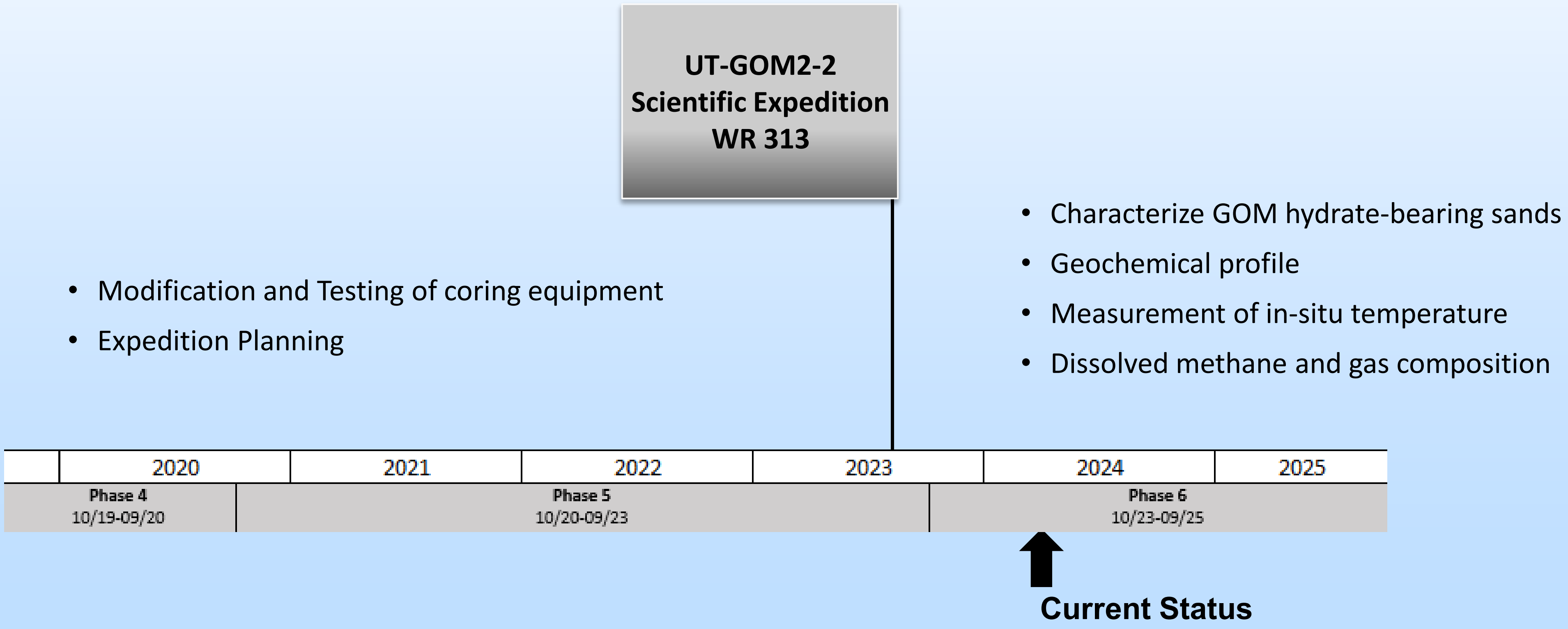
National Energy Technology Laboratory
Resource Sustainability Project Review Meeting
April 2-4, 2024

Presentation Outline

- Project Overview
- Technical Approach
  - Scientific Goals
  - Site location
  - Drilling and Coring Program
  - Results
  - Reporting Plan
- Summary

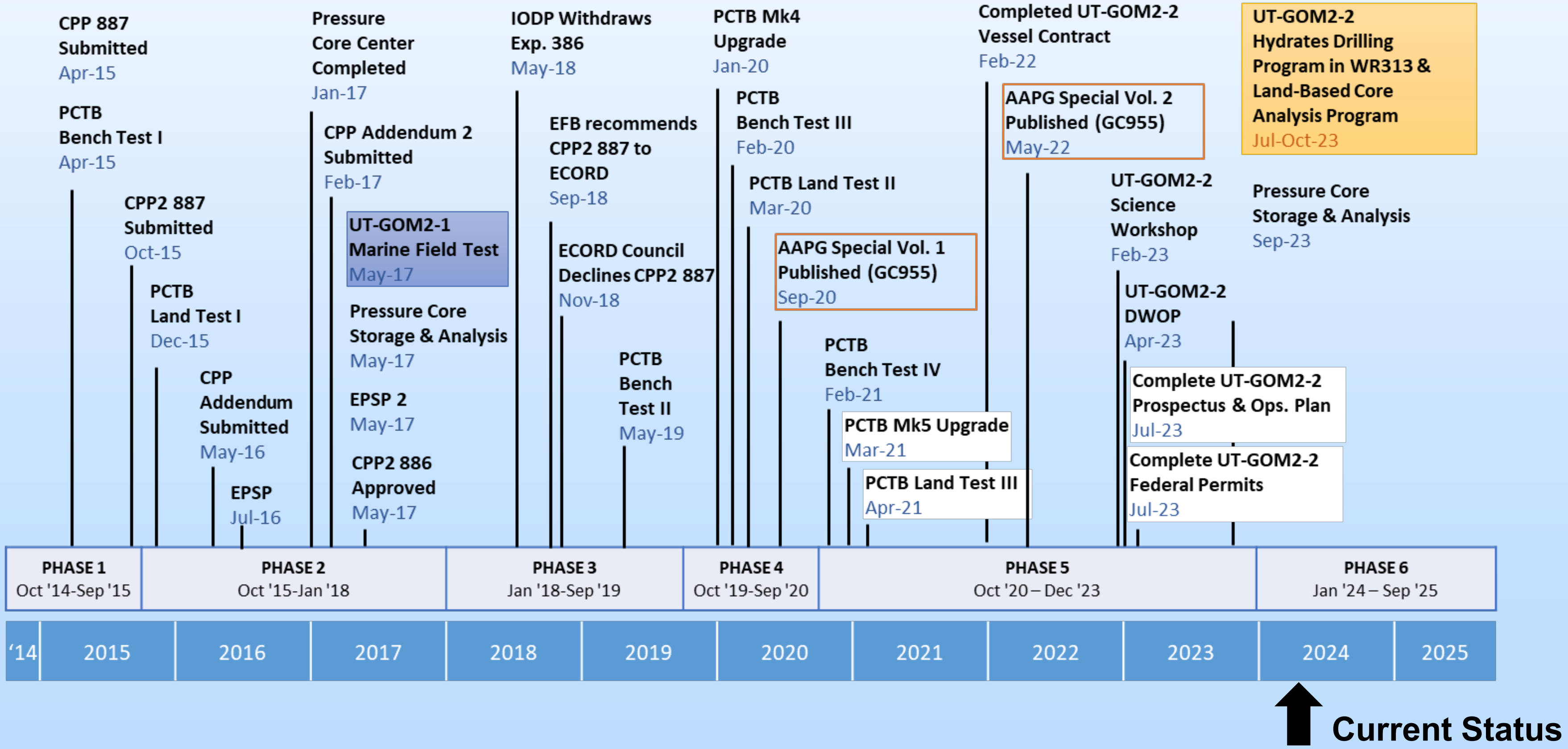
GOM2 Scientific Goals, Dates, Funding

- **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**



GOM2 Scientific Goals, Dates, Funding

- **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**



Project Participants

Pressure Core Analysis

Seismic
Gas Analysis

Geomechanics

Pressure Core Analysis;
Geomechanics

University of
New Hampshire

Sedimentology

Microbiology

In situ Measurements

Regional Mapping,
Permitting Support

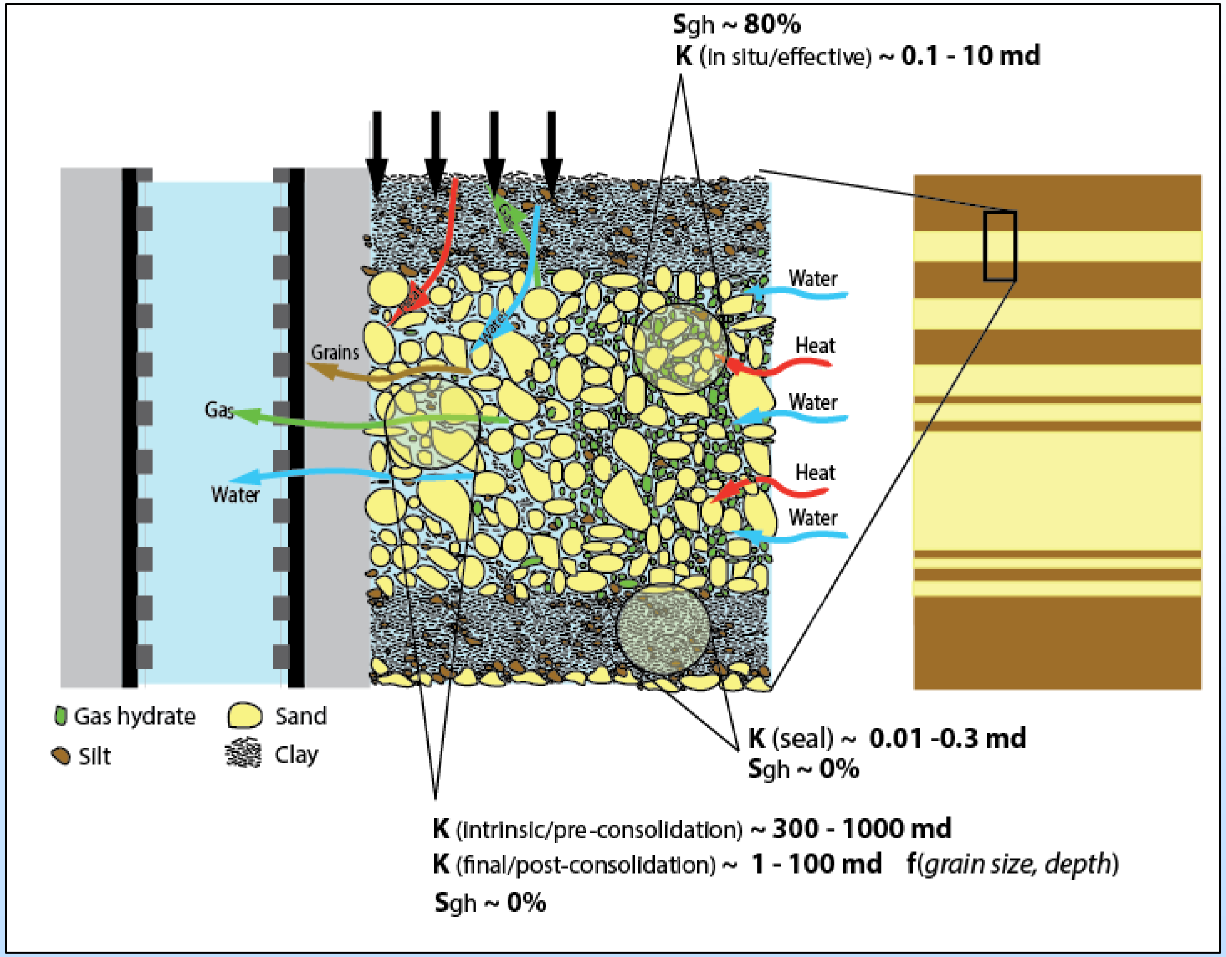
Pore Water
Geochemistry

Core Analysis

Accomplishments to Date

- **Successful Field Execution: GOM2-1 and GOM2-2**
- **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**
- **Executing Shore Based Core Analysis Program for GOM2-2**

UT-GOM2-2 Science Objective 1: . Understand Reservoir System



Modified from Boswell & Collet, 2016

Steps:

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

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

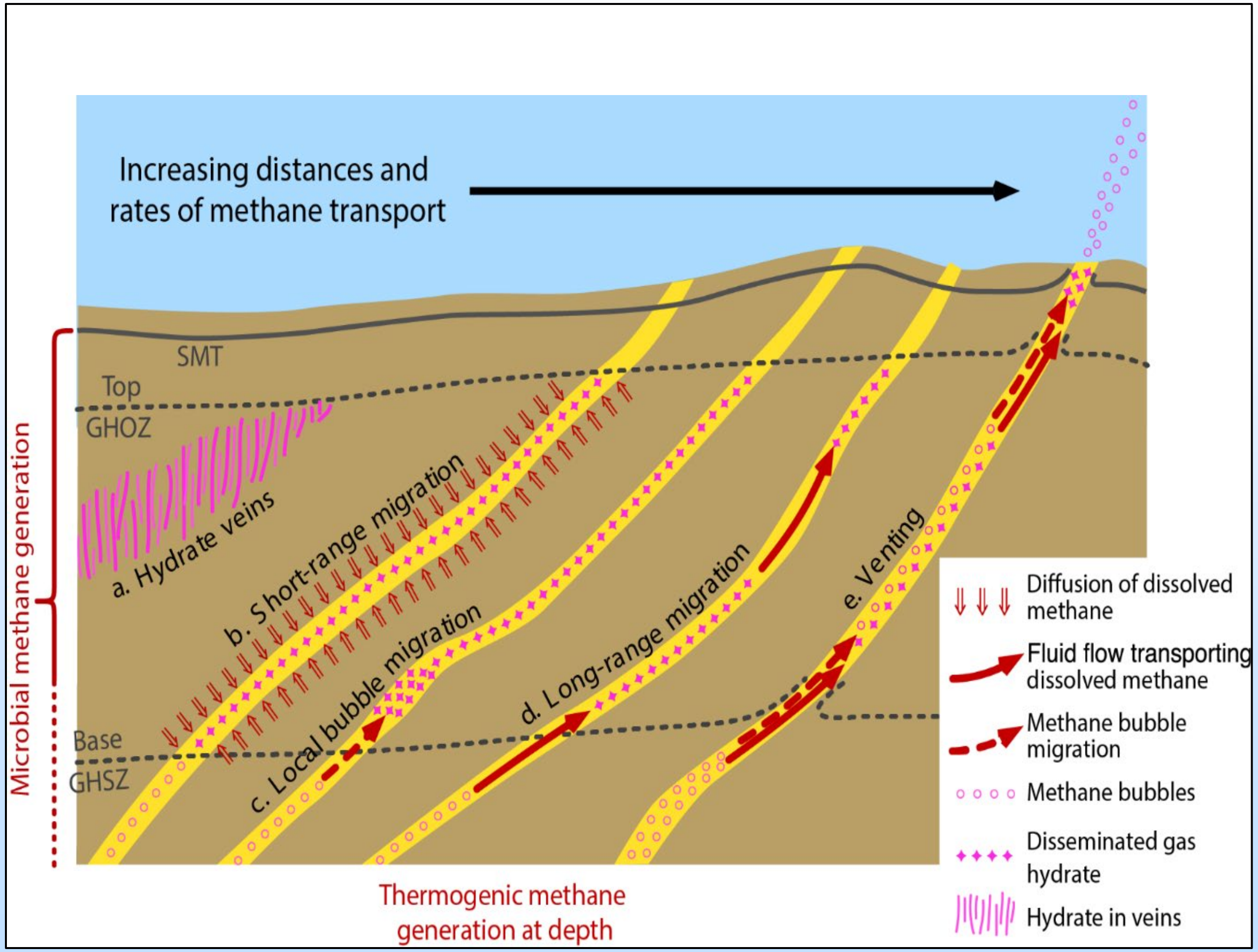
- **Material behavior**

permeability, compression, capillary behavior, strength

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

UT-GOM2-2 Science Objective 2: . Understand Basin System

Understanding the Basin System



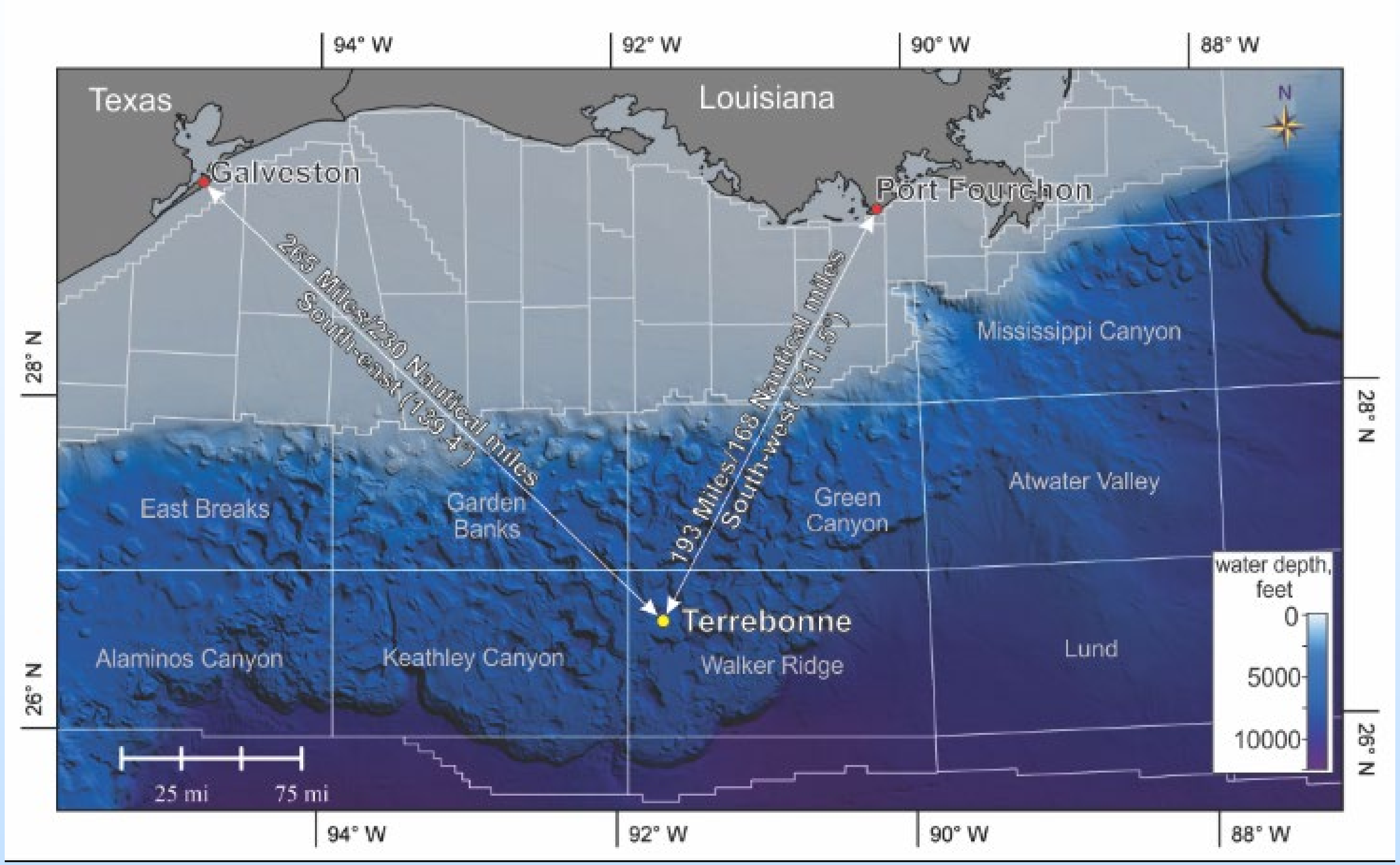
Malinverno & Goldberg, 2015

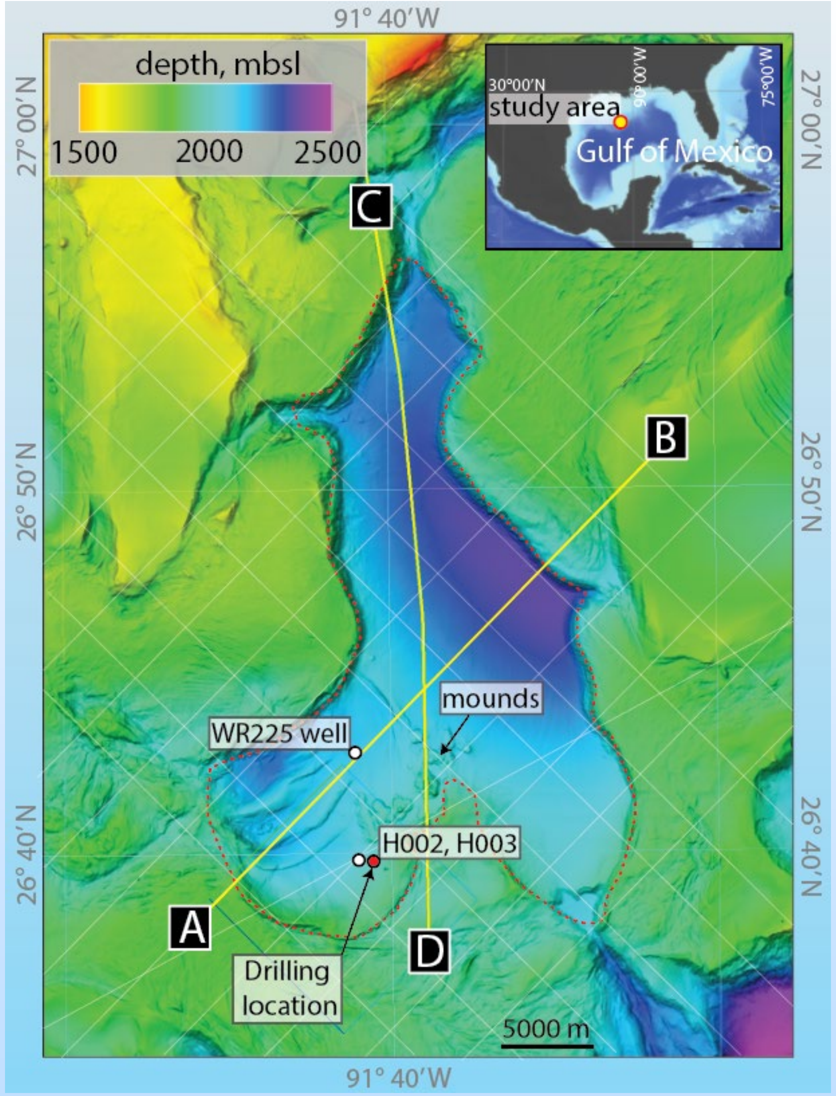
Acquire Depth Profile:

- **Collect** cores, gas/pore waters, 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

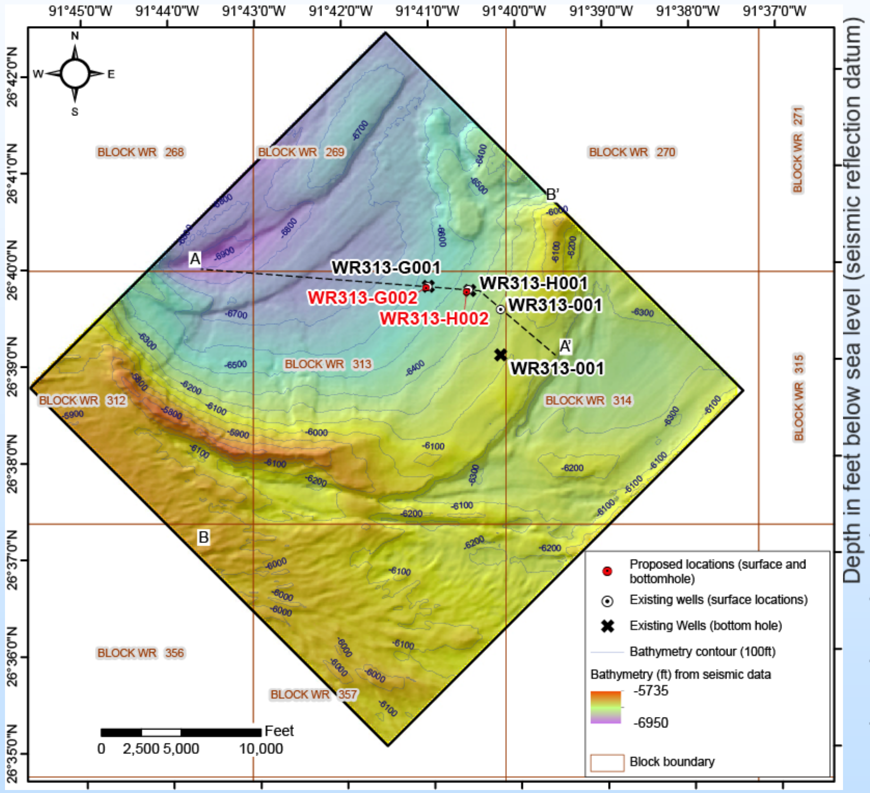
GOM2-2 Expedition: Terrebonne Basin, Gulf of Mexico

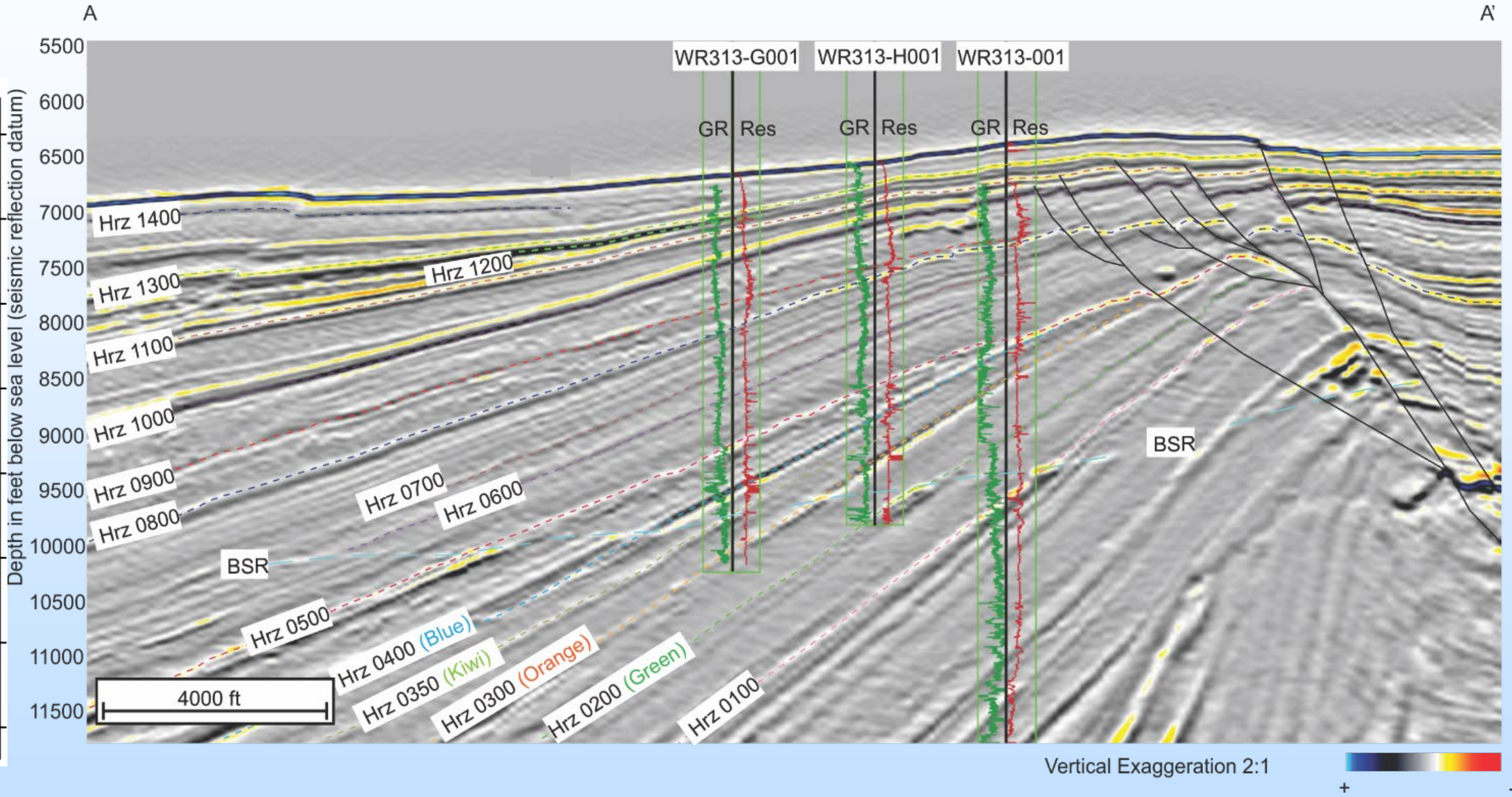
Location: Terrebonne Basin, northern Gulf of Mexico



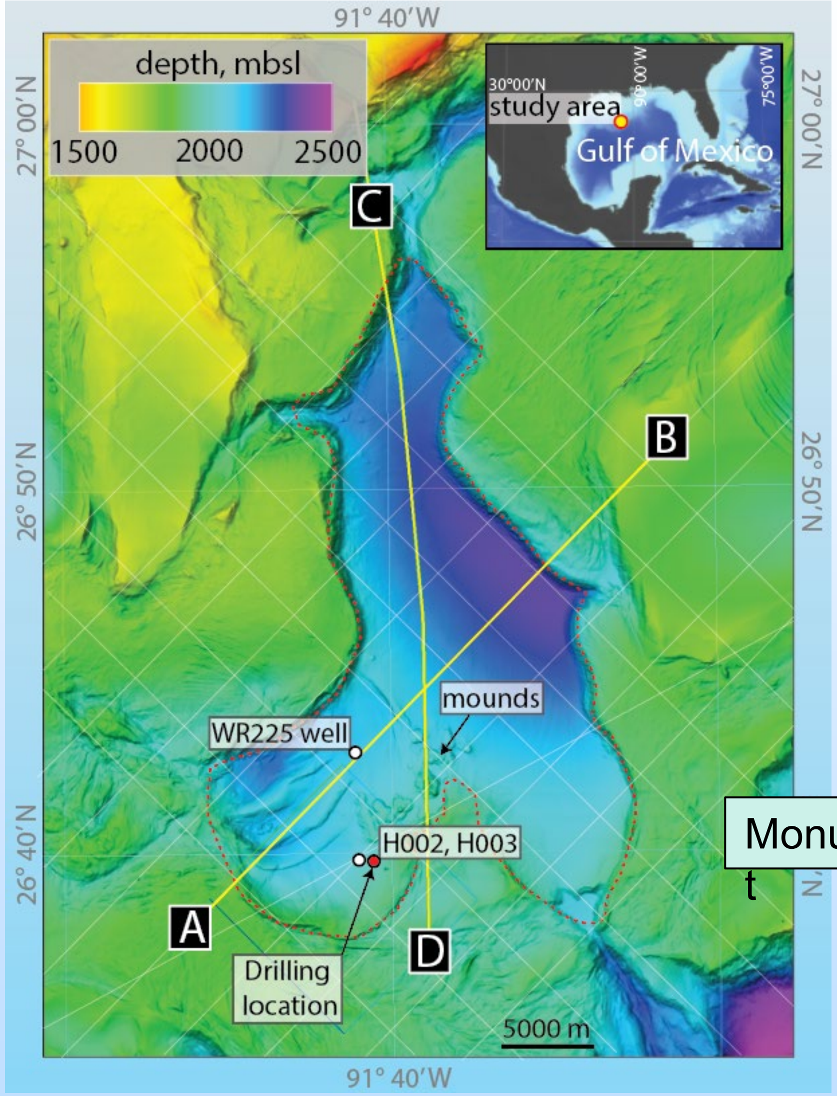


Terrebonne Basin

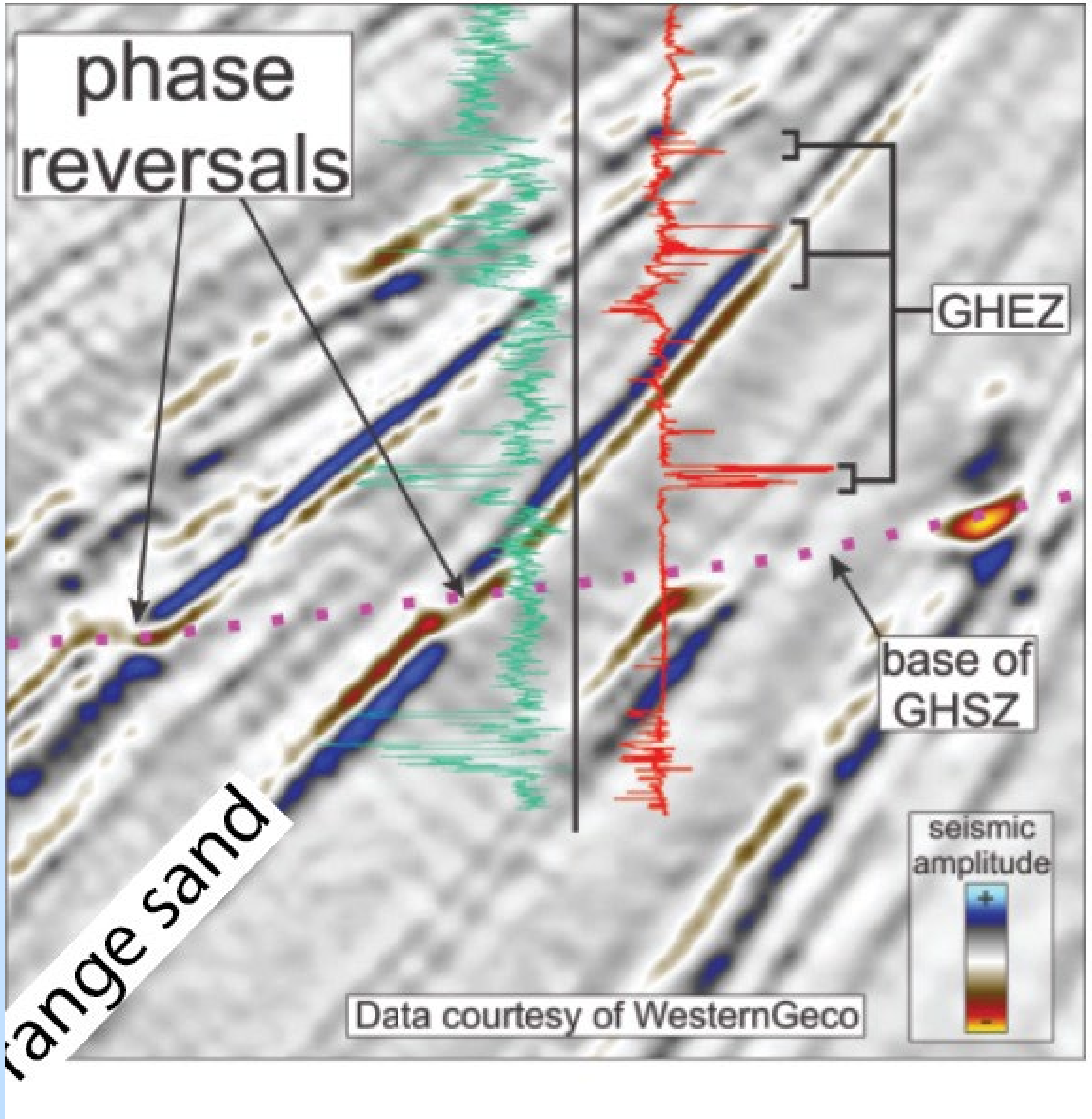




The Terrebonne Basin, northern Gulf of Mexico



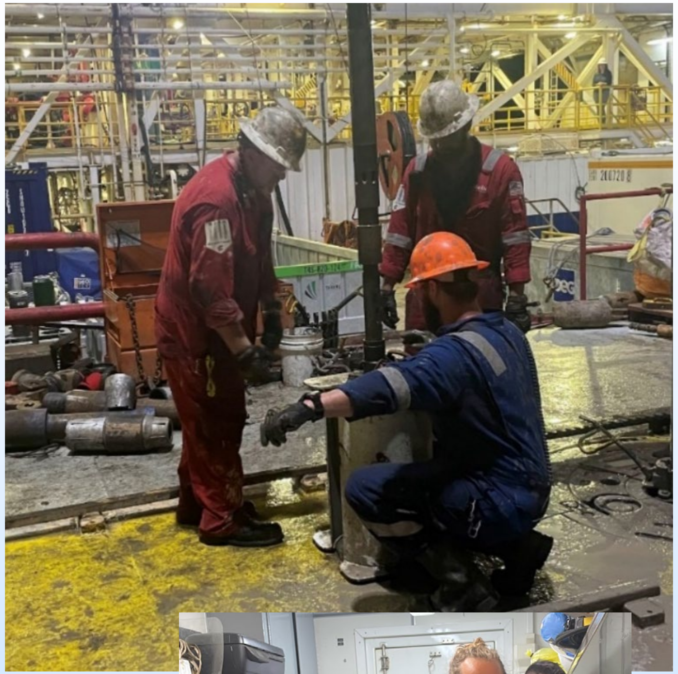
Monumen
t



Vessel and ‘Dockside’ Drilling Program

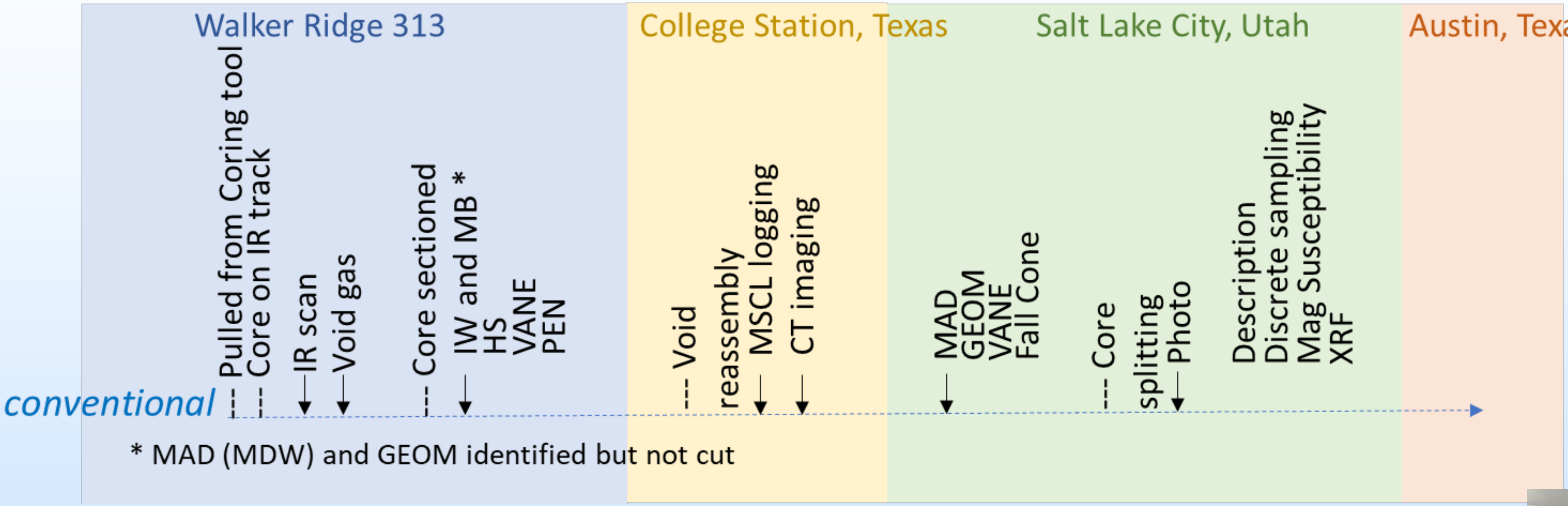
Offshore

Sites: WR313 H002 and H003
Dates: July 30-Sept 1, 2023
Vessel: Helix *Q-4000*
Duration: 34 days off-shore

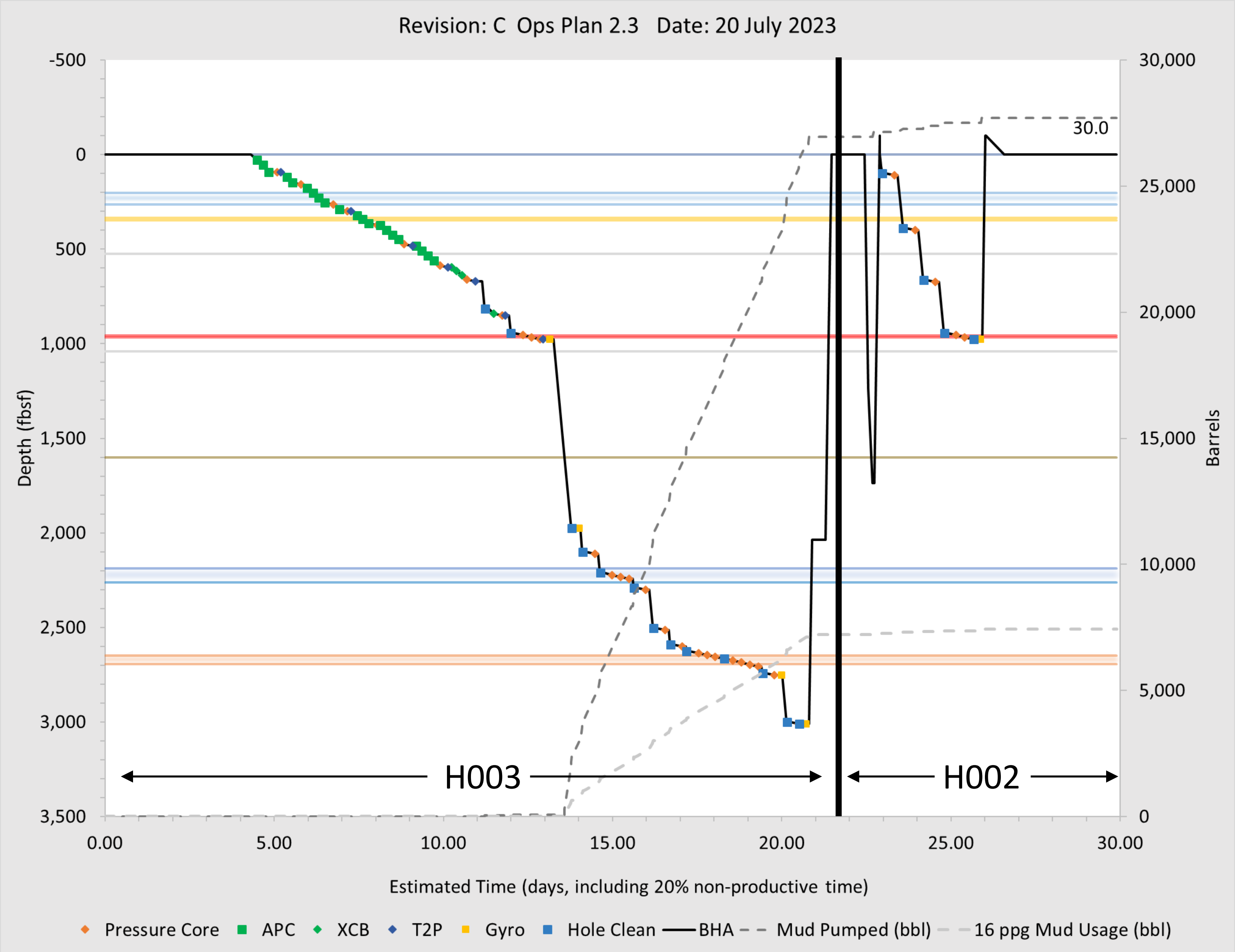




Vessel and ‘Dockside’ Drilling Program

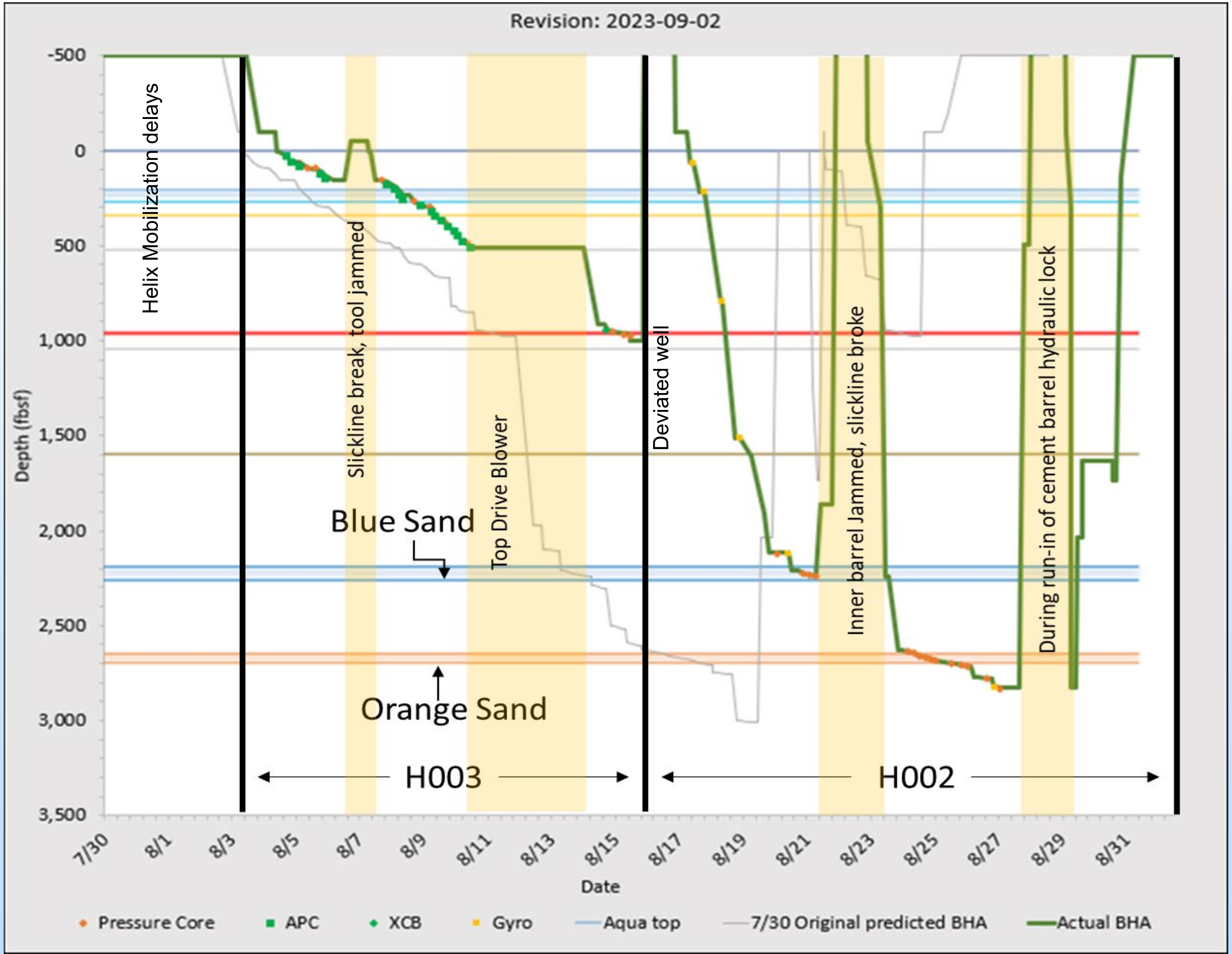
‘Dockside’ - College Station, TX and Salt Lake City, UT



Drilling and Coring Operations: The Plan

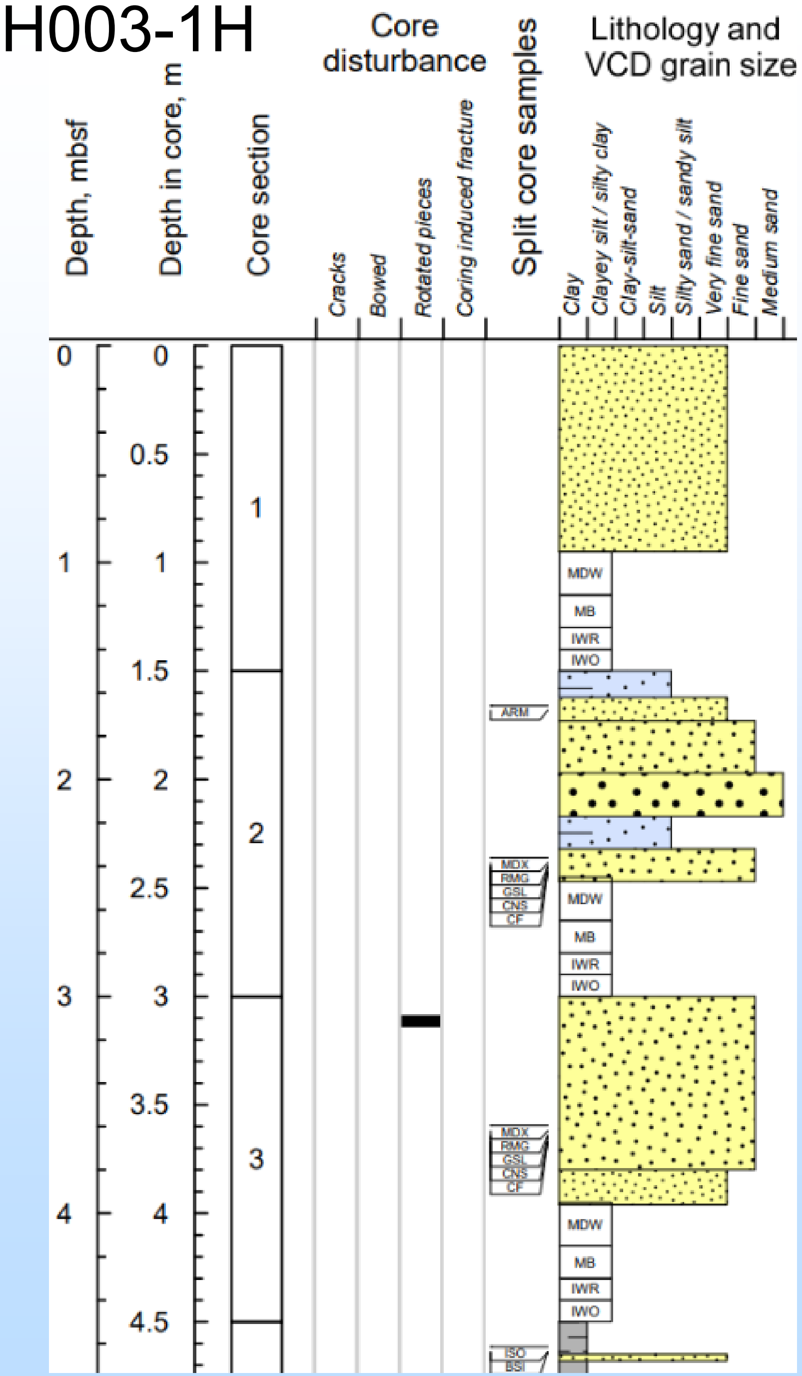


Drilling and Coring Operations: Reality



The Culprit

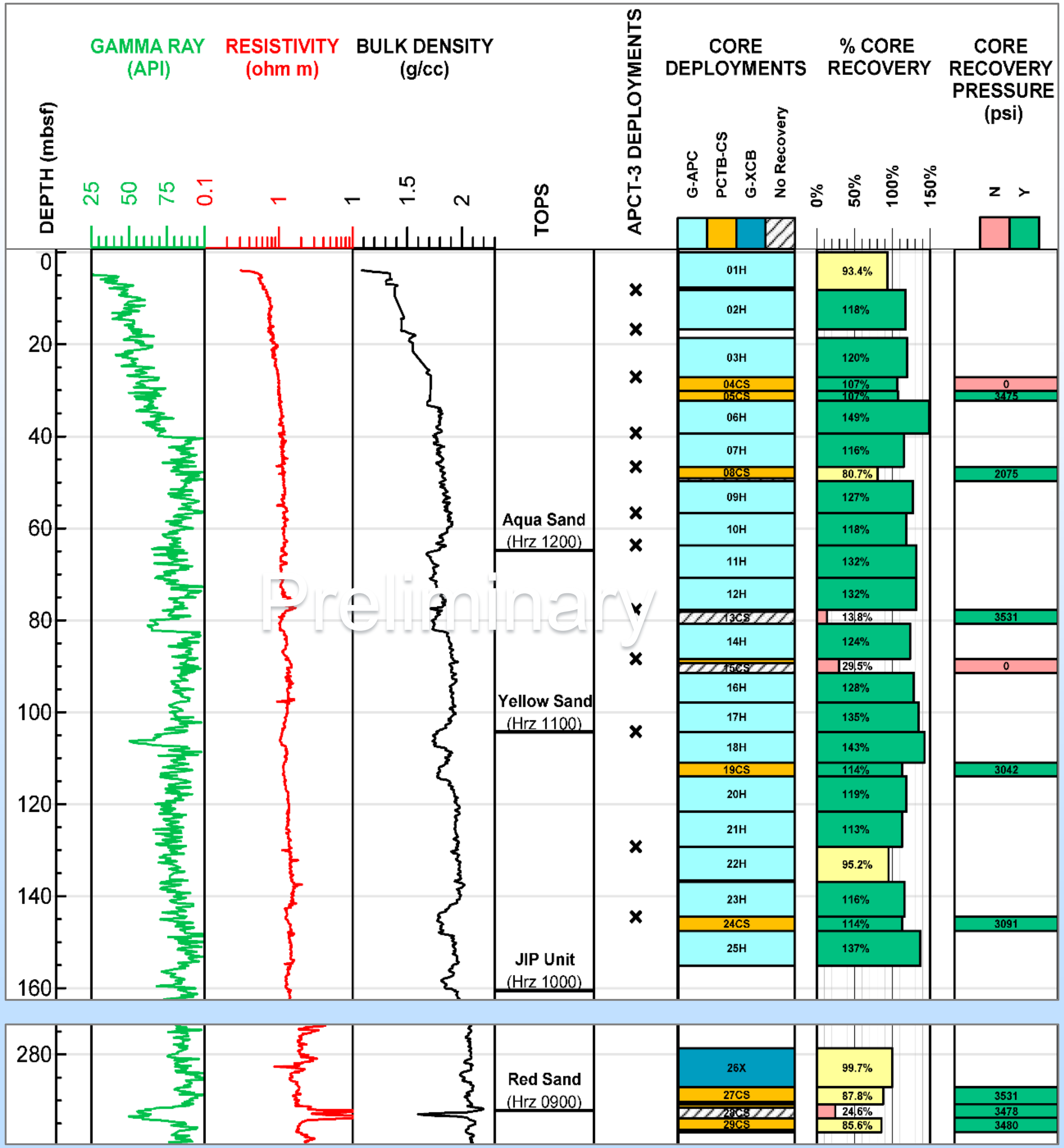
Section 1
Section 2
Section 3



H003-1H
Depth, mbsf
Depth in core, m
Core section
Core disturbance
Cracks
Bowed
Rotated pieces
Coring induced fracture
Split core samples
Lithology and VCD grain size
Clay
Clayey silt / silty clay
Clay-silt-sand
Silt
Silty sand / sandy silt
Very fine sand
Fine sand
Medium sand
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
1
2
3
MDW
MB
IWR
IWO
ARM
MDX
RMG
GSL
CNS
CF
ISO
BSI

Preliminary Results

H003 Coring



Shallow Coring Program

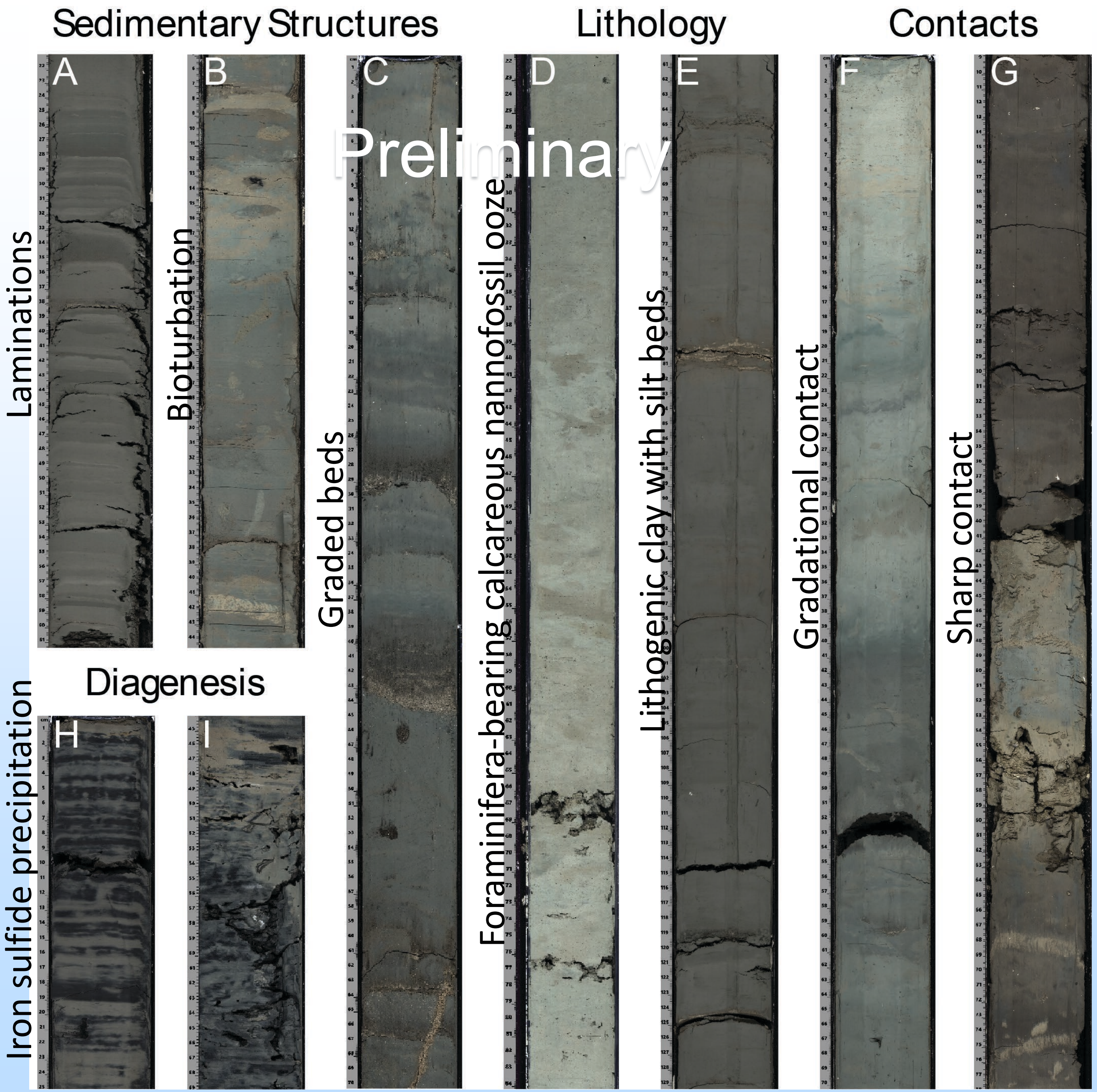
- Continuous coring from the seafloor to 508 fbsf (155.1 mbsf) including:
  - APC cores with full penetration and high recovery
  - Pressure cores that characterized the dissolved methane profile
- 12 APCT temperature measurements captured the in-situ temperature

Lithostratigraphy (0-300 mbsf)

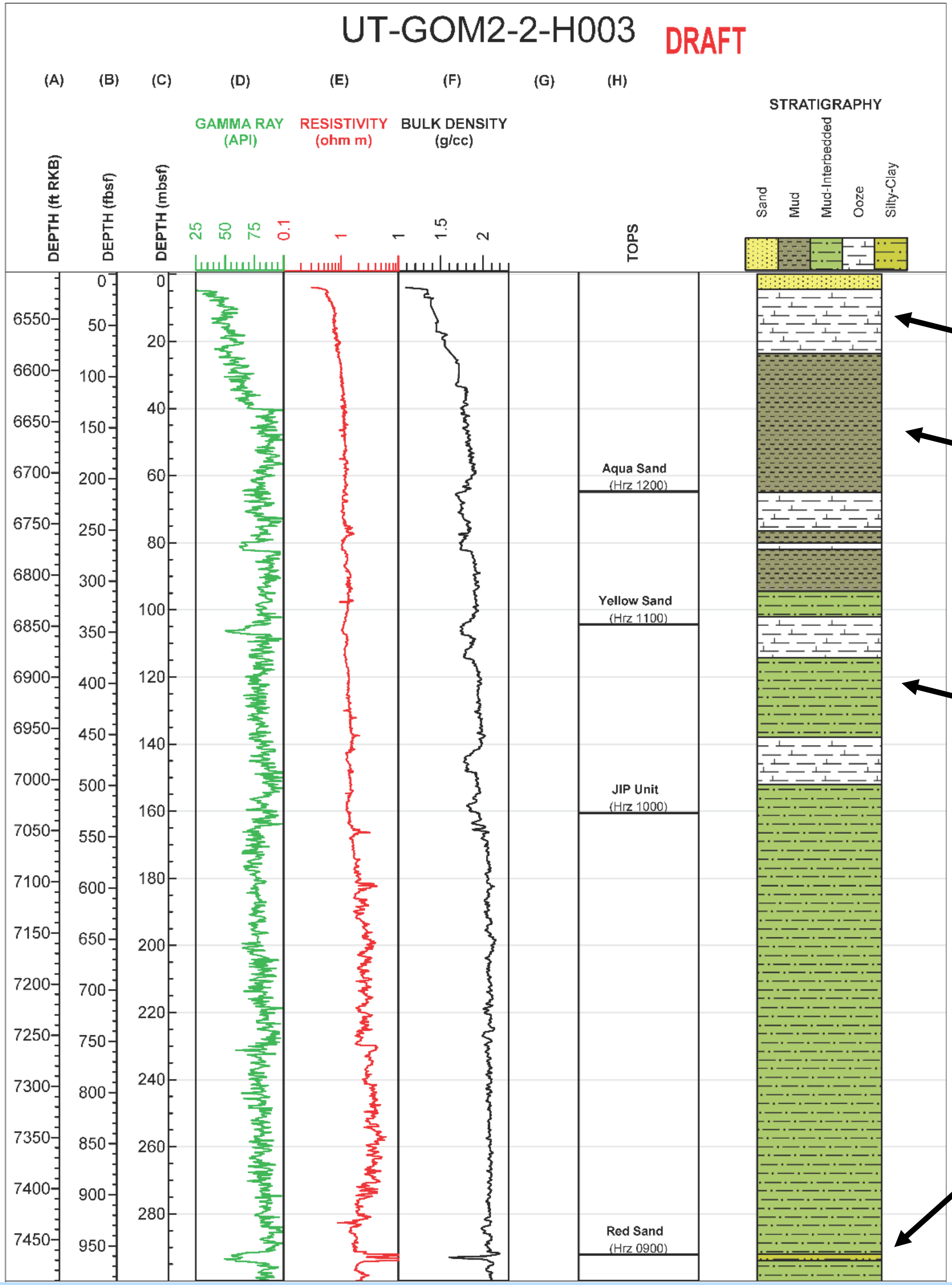
Most of the clay dominated intervals vary in composition between two end members:

- “carbonate oozes”: calcareous nannofossil oozes +/- foraminifera

- “lithogenic clays”: quartz-rich, carbonate lithic-rich clays, with feldspars (microcline and plagioclase) and igneous lithics



Lithostratigraphic Interpretation

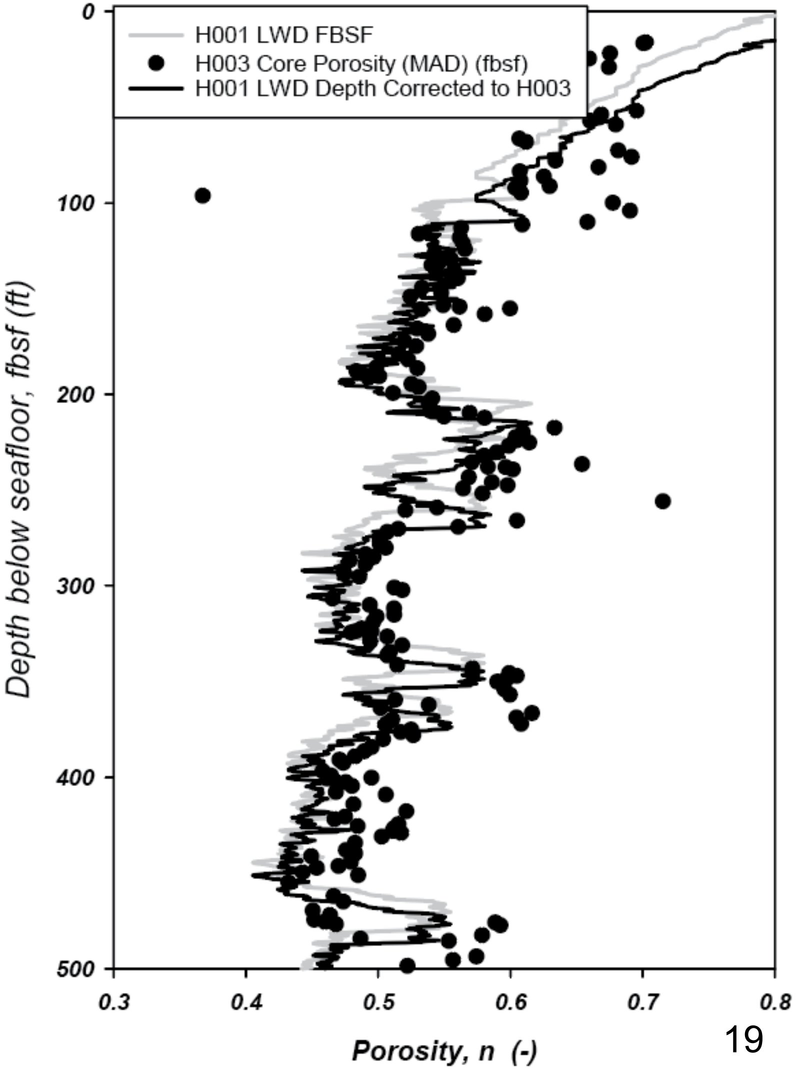


Carbonate Ooze

Lithogenic Clay

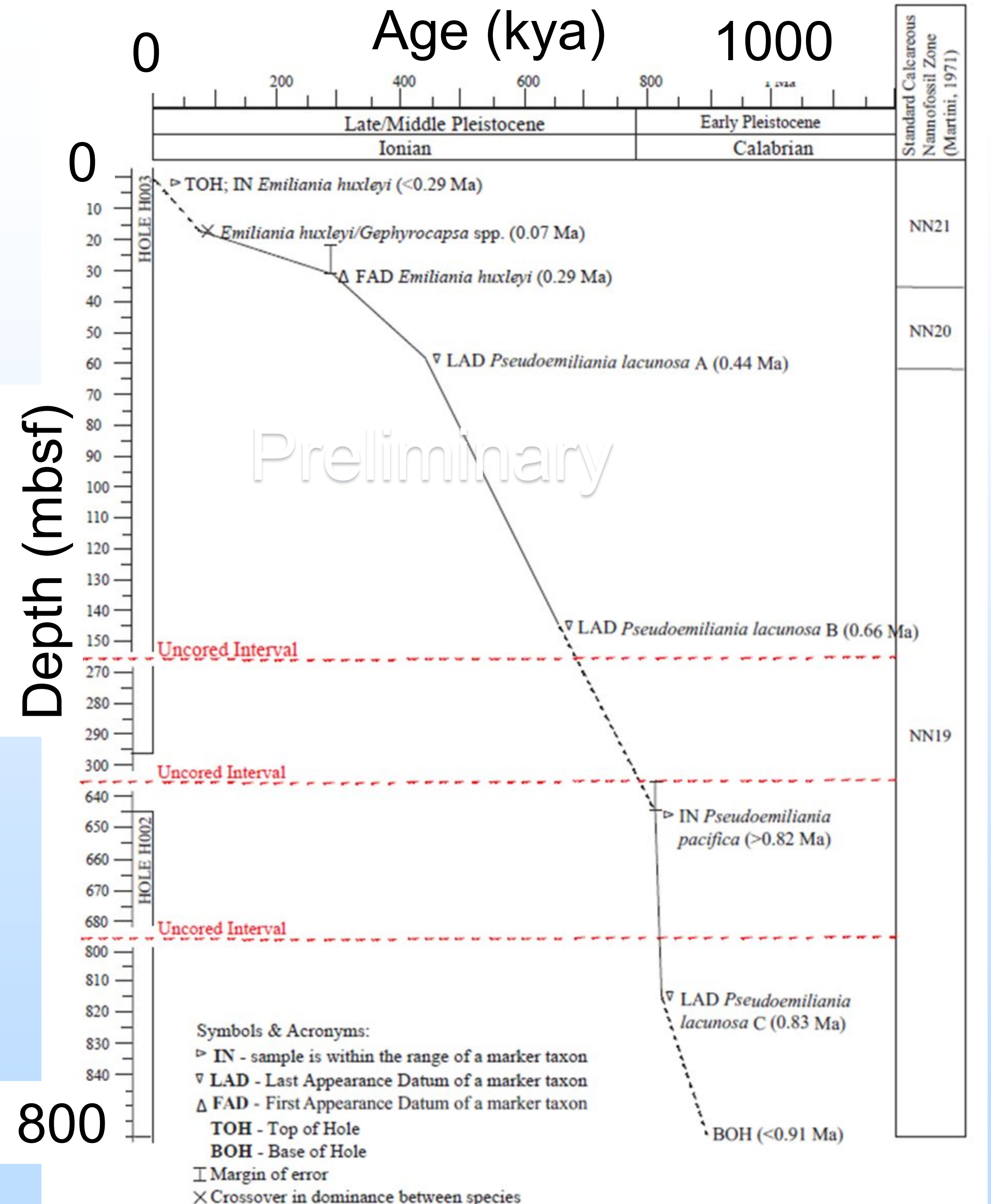
Lithogenic Clay and occasional silts & sands.

Sand.



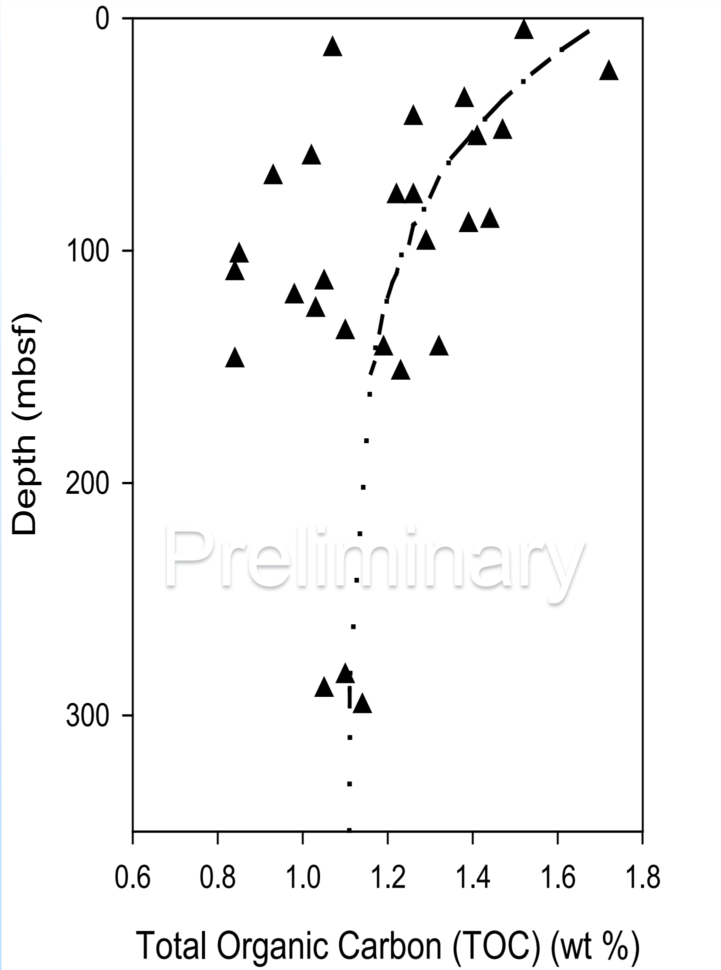
Biostratigraphy

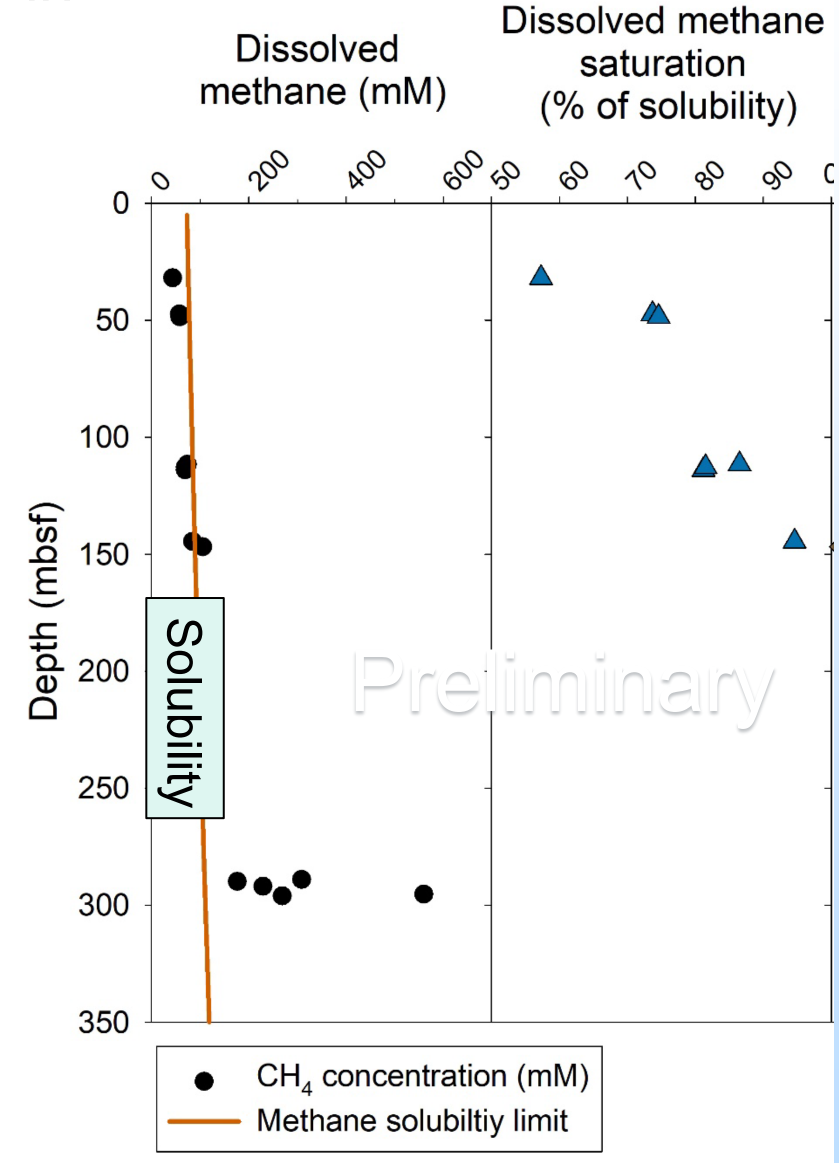
- Pleistocene Age Strata
- Rapidly formed basin (1mm/yr)
- Sedimentation rate rapidly increases at the Blue to Orange interval
- Ages roughly compatible with previous predictions



The Biogenic Factory?

Peak methanogenesis in the first 150 mbsf?

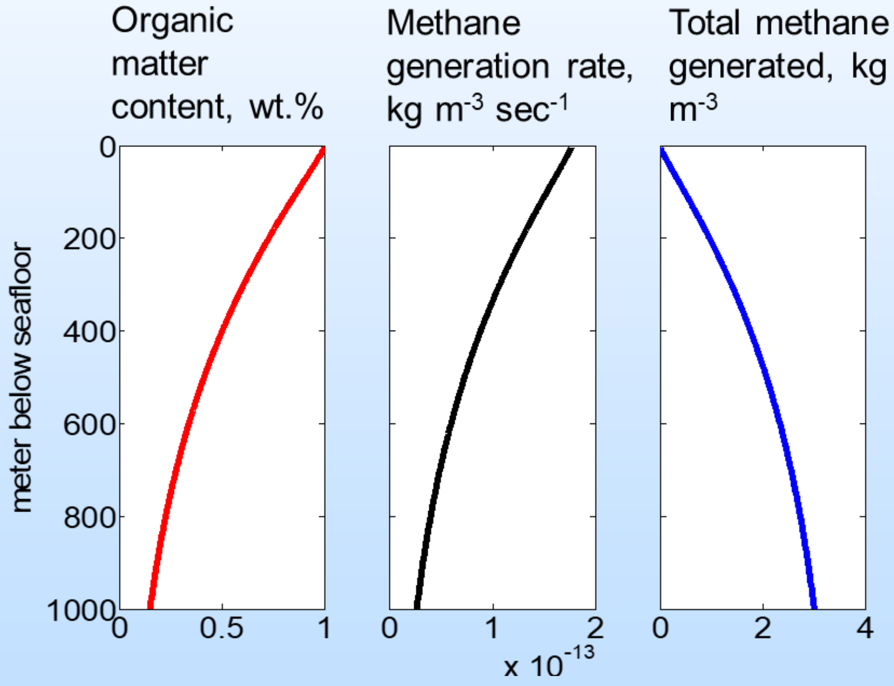




$$q_{bio}^{m} = A\lambda_{bio}\alpha_{bsrz}e^{-\lambda_{bio}t}$$

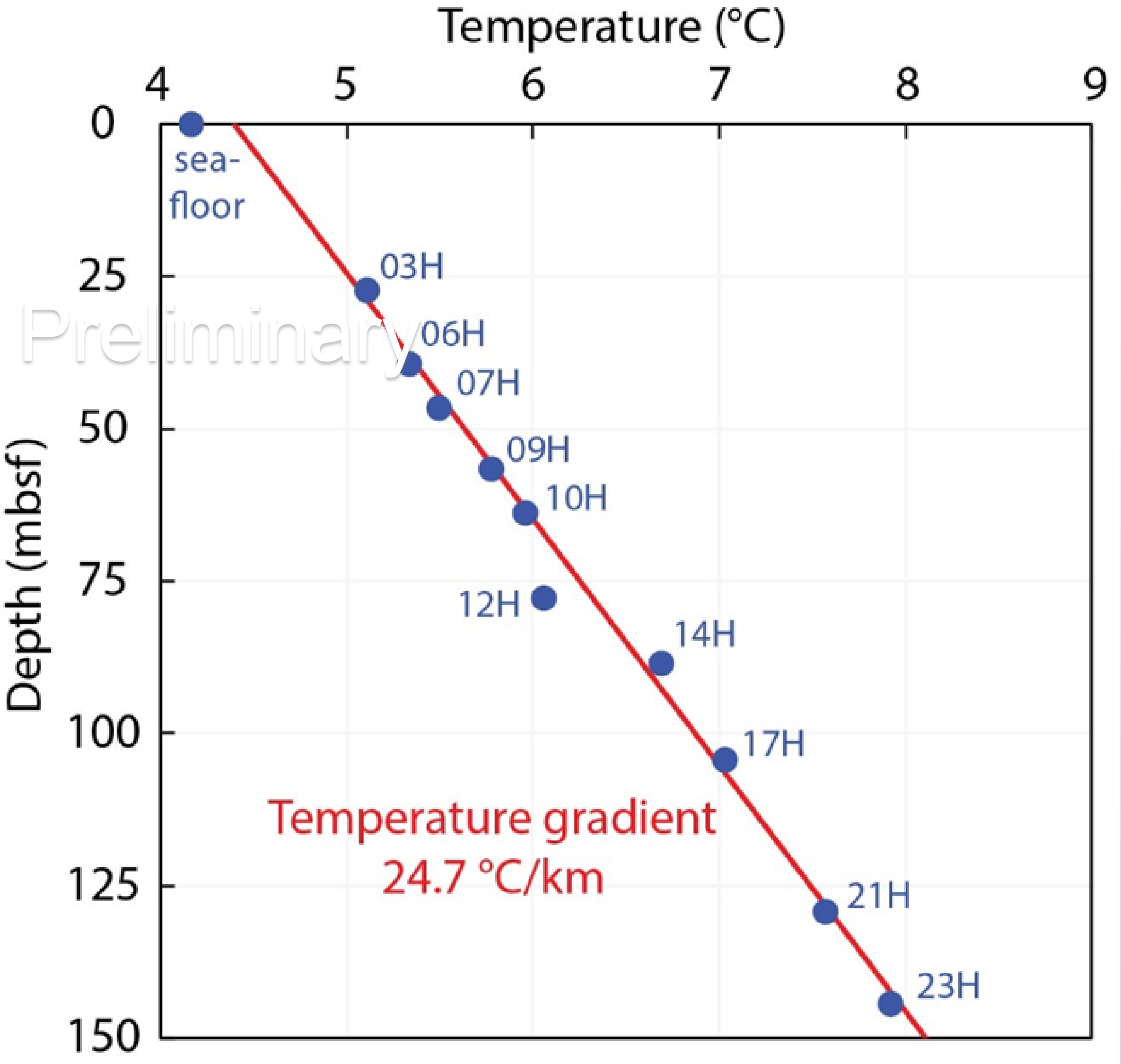
reaction rate constant

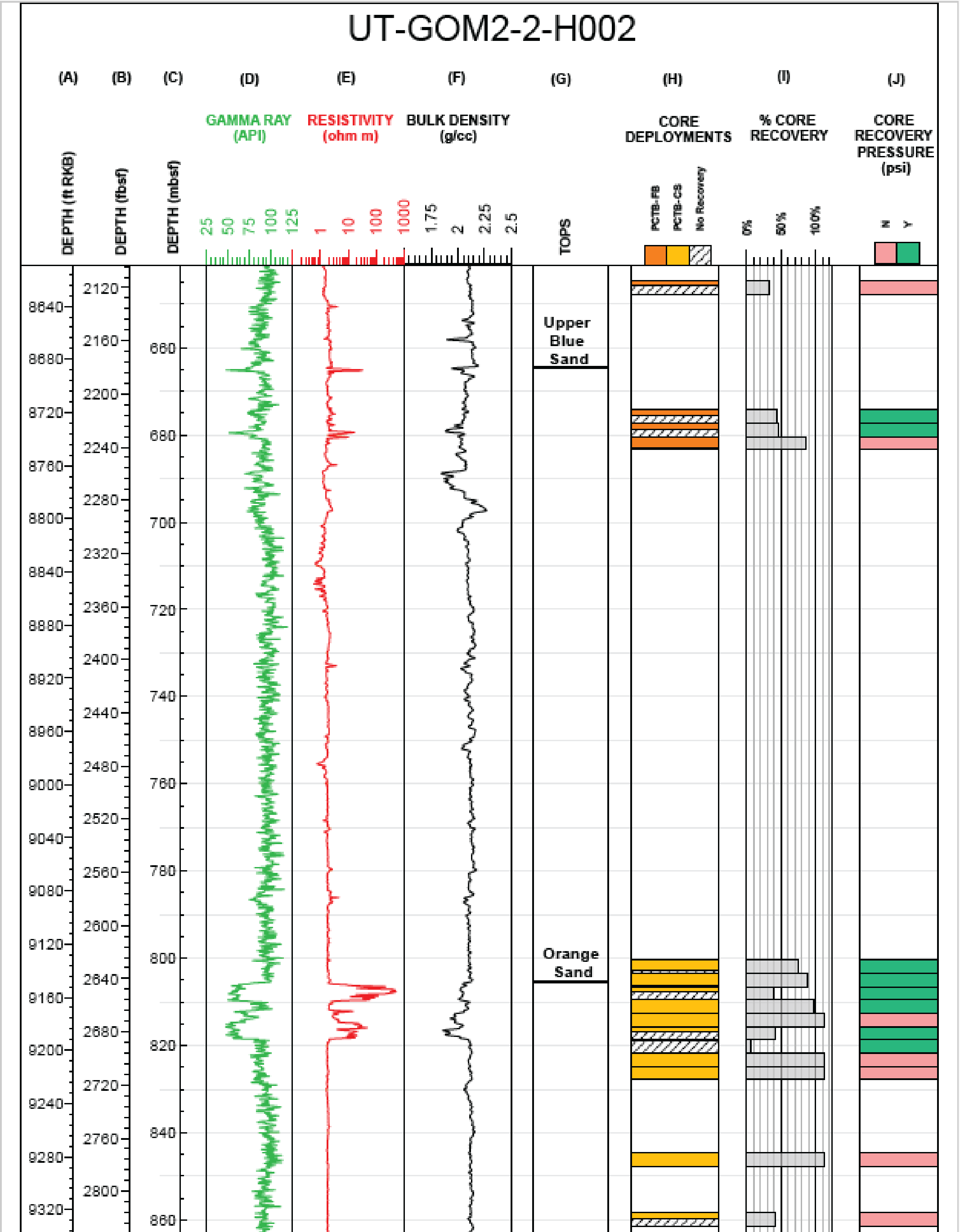
organic carbon content



In-situ Temperature

- Higher temp. gradient than predicted by 1-D model
- Contribution of salt structure to heat flow



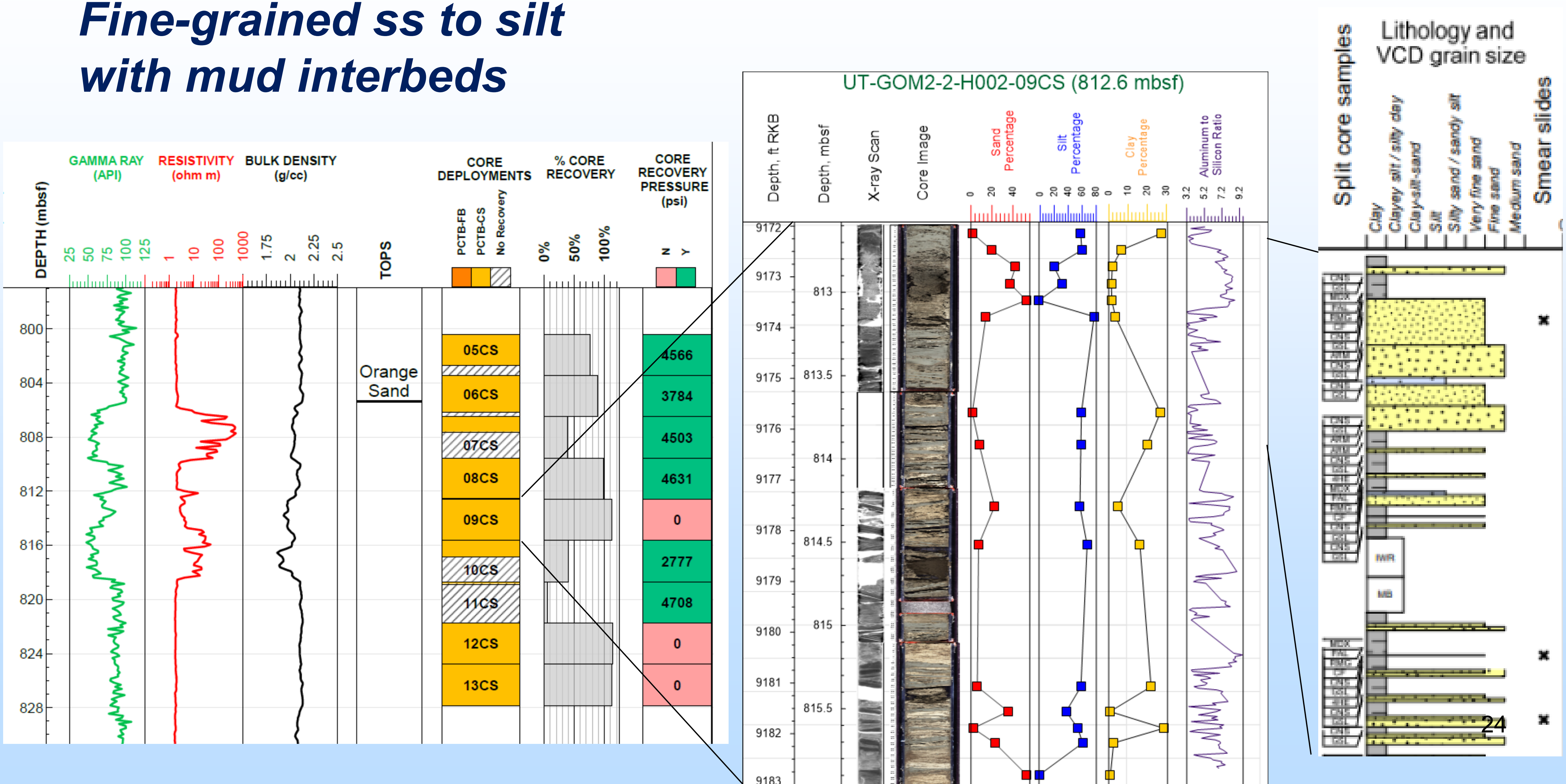


Deep Coring Program

- Recovered Pressure Core across two hydrate-bearing reservoirs
  - **Relatively low recovery in sand bearing intervals.**

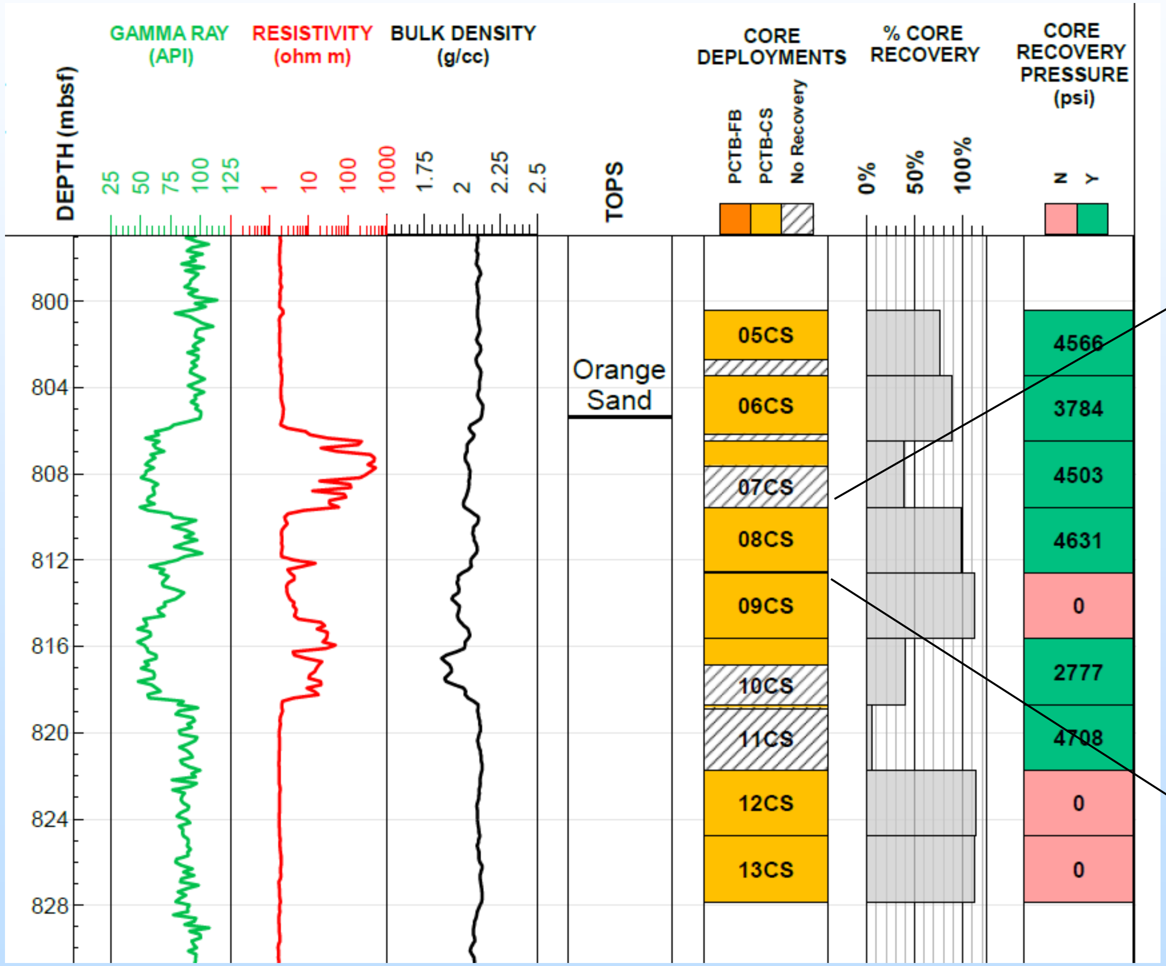
Orange Sand Lithology

Fine-grained ss to silt with mud interbeds

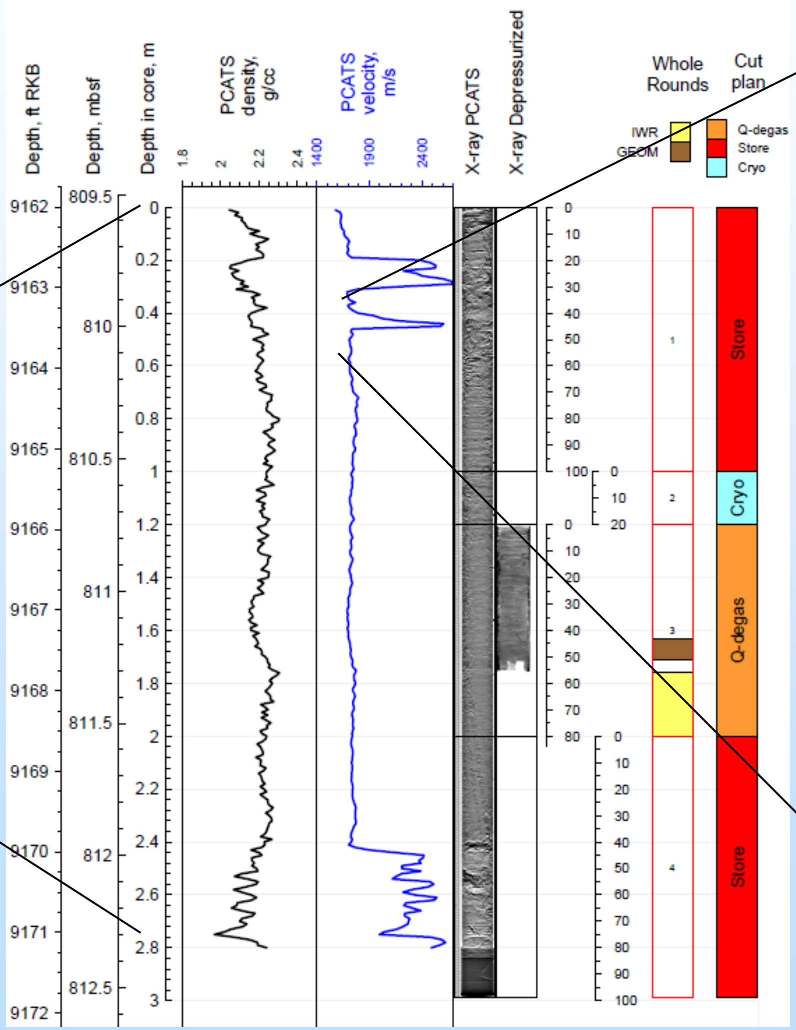


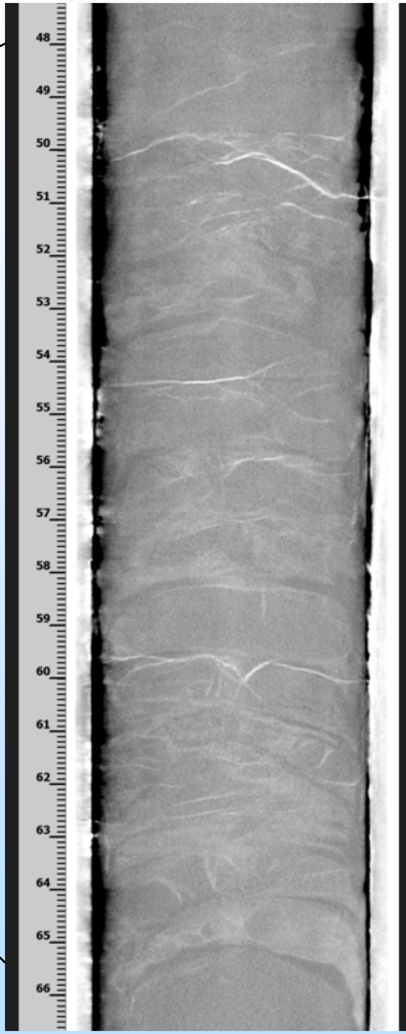
Pressure Cores of Hydrate Bearing Sand

H002 Coring



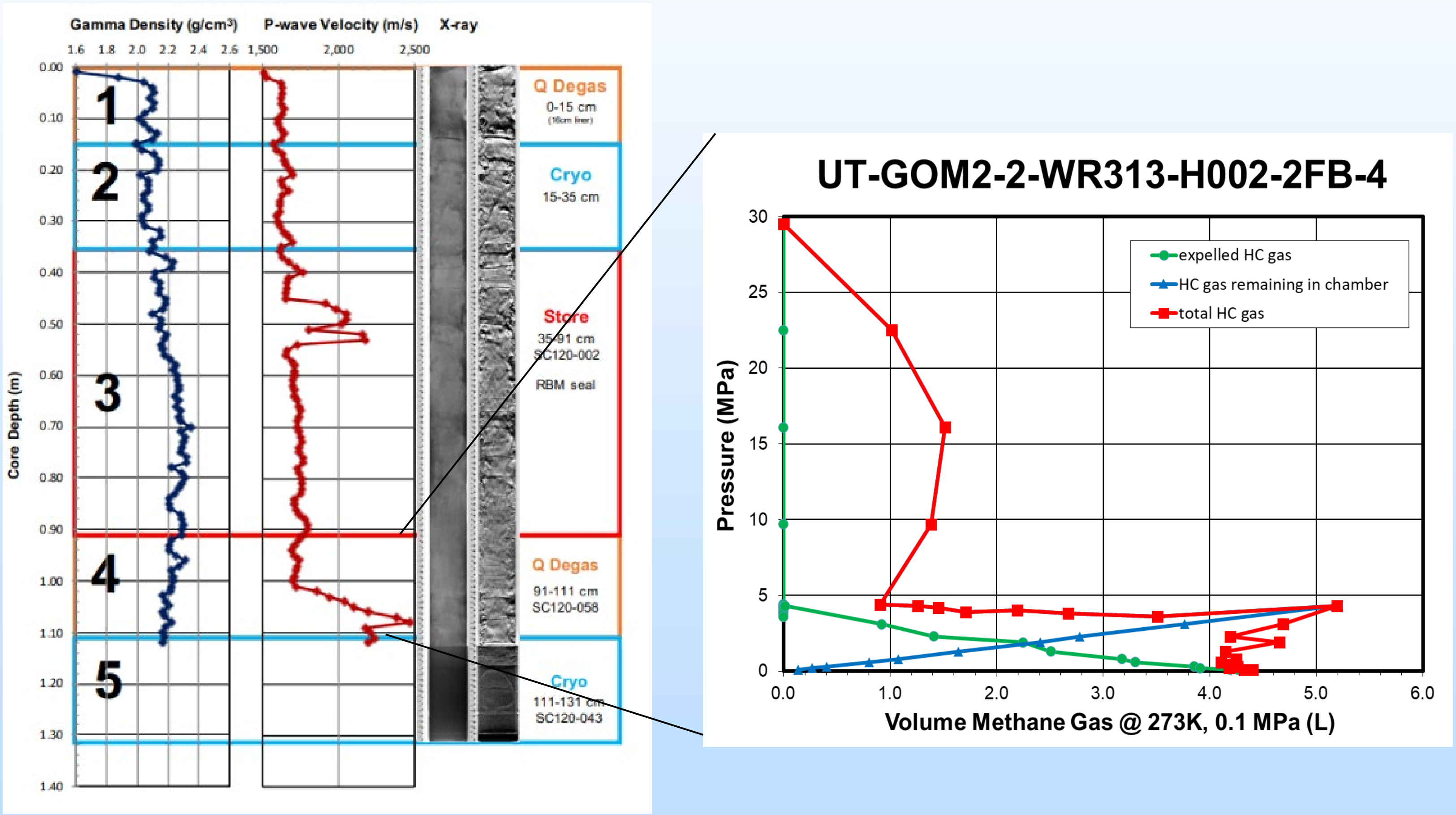
H002-08CS





Preliminary Results

Hydrate Saturation – Transition into the hydrate-saturated Upper Blue sand



675.13-675.33 mbsf

Degassed over 29.9 hours

S_h = 24.4%

Shore-based analysis program

Work on Science Objectives continues in BP6…

Pressure Cores (University of Texas)
- Gamma Density
- P-wave Velocity
- CT Imaging
- Hydrate Saturation
- PW Dissolved Methane
- Permeability
- Compressive Strength
- TBD: Micro-Raman
- TBD: Microbiology

Working Halves (University of New Hampshire; Tufts University)
- Smear Slide Descriptions
- Course Fraction Microscopy
- Biostratigraphy: Secondary
- CHNS/TOC
- Isotopic Analysis
- Biogenic Silica
- Formamifera
- Carbon Nodules
- Rock Magnetism
- Grain Size: Hydrometer
- MAD: Grain Density
- XRD including clay details
- Grain Size: Laser Particle

Pore Water whole rounds (University of Washington)
- Salinity
- Alkalinity and pH
- DIC
- DOC
- Chlorinity
- SO_4, Br, F
- Major cations (Na, Ca, Mg, 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
- $\delta^{13}C$-DIC
- ^{34}S-H_2S
- $\delta^{7}Li$
- $\delta^{37}Cl$

MDX and GEOM whole rounds (Tufts University)
- Water content
- Density
- Grain Size: Settling method
- Atterberg Limits
- Constant Rate of Strain
- XRPD

MBIO whole rounds (Oregon State University)
- DNA sequencing -diversity
- RNA sequencing -activity
- Methanogenesis gene frequency
- Contamination
- Cell counts
- Single-Amplified Genomics
- Microbial-induced carbonate precipitation
- Heterotrophic microorganisms

Collected gas samples (USGS — science for a changing world; Ohio State)
- Hydrocarbons (C1-C5)
- Isotopes: $\delta^{13}C$-C_2H
- Hydrocarbons (C1-C6, CO_2)
- Noble Gases: ^{4}He, ^{20}Ne, ^{36}Ar, Kr, and Xe
- Isotopes: $\delta^{13}C$-CH_4, δD-CH_4, $\delta^{13}C$-CO_2
- TBD: Clumped Isotopes: $^{13}CH_3D$, $^{12}CH_2D_2$

Plan for Reporting

- **The UT-GOM2-2 Scientists, UT-GOM2-2 Hydrate Coring Expedition Preliminary Report – *April 30, 2024***
- **The UT-GOM2-2 Scientists, Proceedings of the UT-GOM2-2 Hydrate Coring Expedition – *Dec 31, 2024***
- **Special Journal Volume on Walker Ridge 313**
  - number of papers in special volume to-be-determined (G3?)
- **Expedition Website**

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

UT-GOM2-2: A Success Despite Challenges

Recognized challenges before execution

1) Permitting (13)
2) Contracting, Insurance, Bonding, UT Approval
3) Drill hole ~3,000 feet below mudline in 6460’ water
   - ~14,000 bbl. mud
   - 10,000 ft of pipe
   - Plug and Abandon
4) Conventional and pressure core, temperature measurements.
5) Mobilize/perform science program 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.

Challenges during execution

- Unexpected shallow sand
- Vessel (top drive) down for 1 week
- Vessel not optimized for drilling/coring
  - Equipment
  - personnel
- Vessel just out of port call.
- Covid
- Continous delays on execution

Summary Slide

- Successfully executed a deepwater hydrate coring expedition
  - ✓ Challenging drilling conditions exacerbated by seafloor sand section
  - ✓ Extraordinary data set to study basin scale microbial gas system
  - ✓ Suite of pressure cores from shallow will illuminate the hydrate reservoir petrophysics.
  - ✓ Exciting science now being done on expedition results
- Integrated effort led by DOE but linking USGS, BOEM, 7 universities, and contractors
- These efforts take long term focused commitment and investment

Thank you!
(appendix slides follow)

Students Supported During the Project

1. Zachary Murphy – UT Austin Graduate Student
2. Camila Van Der Maal – UT Austin Undergraduate Student
3. Addison Savage – UT Austin Undergraduate Student
4. Colton Hayden – UT Austin Undergraduate Student
5. Nicholas Adelberg – UT Austin Undergraduate Student
6. Nicholas Mills – UT Austin Post-Doc
7. Rachel Coyte – Ohio State Post-Doc
8. Saffron Martin – Ohio State Undergraduate Student
9. Muhedeen Lawal – Ohio State Post-Doc
10. Irita Aylward – U. Washington Graduate Student
11. Taylor Walton – U. Washington Graduate Student
12. Reese Miller – U. Washington Graduate Student
13. Man-Ying Tsang – U. Washington Post-Doc
14. Kelly Shannon – Oregon State Graduate Student
15. Jessica Buser – Young, Oregon State Graduate Student
16. Camille Sullivan – UNH Graduate Student
17. Kayla Tozier – UNH Graduate Student
18. Li Wei – Columbia University (LDEO) Post-Doc
19. Cathal Small – Tufts University Graduate Student
20. Ethan Petrou – Oxford Post-Doc

2023 Publications

- Bhandari, A.R., Cardona, A., Flemings, P.B., Germaine, J. T. (In Review). Geomechanical behavior of sandy silt from Green Canyon 955 hydrate reservoir - Deepwater Gulf of Mexico for gas hydrate dissociation, Marine and Petroleum Geology
- Cardona A., Bhandari A., Heidari M. and Flemings P.B. (2023). The viscoplastic behavior of natural hydrate bearing sediments under uniaxial strain compression (K0 loading), Journal of Geophysical Research: Solid Earth, v. 128, e2023JB026976, https://doi.org/10.1029/2023JB026976
- Naim, F., Cook, A.E., Moortgat, J. (2023) Estimating P-wave Velocity and Bulk Density in Near-seafloor Sediments Using Machine Learning, Energies. 16(23) doi:10.3390/en16237709. https://www.mdpi.com/1996-1073/16/23/7709
- Portnov, A., You, K., Flemings, P.B., Cook, A.E., Heidari, M., Sawyer, D.E. and Bünz, S. (2023) Dating submarine landslides using the transient response of gas hydrate stability. Geology. doi: 10.1130/G50930.
- Portnov, A., Flemings, P. B., You, K., Meazell, K., Hudec, M. R., and Dunlap, D. B., 2023, Low temperature and high pressure dramatically thicken the gas hydrate stability zone in rapidly formed sedimentary basins: Marine and Petroleum Geology, v. 158, p. 106550.
- Varona, G. M., Flemings, P.B., Portnov, A., 2023, Hydrate-bearing sands record the transition from ponded deposition to bypass in the deep-water Gulf of Mexico, Marine and Petroleum Geology, v. 151. https://doi.org/10.1016/j.marpetgeo.2023.106172

2023 Conference Presentations/Abstracts

- Buser J.Z., Shannon K. and Colwell F. The Microbiome of Methane Hydrate-Bearing Sediments, a Global Meta-Analysis. OS21B-1425. Poster presented at the Fall Meeting of the American Geophysical Union. December 2023.
- Cardona, A., Fang, Y., You, K., and Flemings, P.B. Relative Permeability of Hydrate-Bearing Sediments: The Critical Role of Hydrate Dissolution. OS21B-1418. Poster presented at the Fall Meeting of the American Geophysical Union. December 2023.
- Collett, T., Boswell, R., Shukla, K., Flemings, P.B., and Tamaki, M. Characterization of deepwater marine depositional systems associated with highly concentrated gas hydrate accumulations in coarse-grained reservoirs. Abstract ID 61. Oral talk presented at International Gas Hydrates Conference (ICGH10). July 2023.
- DiCarlo, D., Murphy, Z., You, K. and Flemings, P.B. Pore Occupancy of Gas Hydrate. OS23A-06. Oral talk presented at the Fall Meeting of the American Geophysical Union. December 2023.
- Kumar, A., Cook, A., Portnov, A., Palmes, S., Frye, M. and Lawal, M. Bottom Simulating Reflections and Pockmark Distribution in the Northern Gulf of Mexico. OS21B-1412. Poster presented at the Fall Meeting of the American Geophysical Union. December 2023.
- Naim, F., and Cook, A. Occurrence of gas hydrate in carbonate mud in Offshore Western Australia. OS23A-02. Oral talk presented at the Fall Meeting of the American Geophysical Union. December 2023.
- Phillips S., and Johnson, J. Tectono-sedimentary controls on early diagenetic methane cycling in the Cascadia accretionary wedge. OS21B-1424. Poster presented at the Fall Meeting of the American Geophysical Union. December 2023.
- Portnov, A., Flemings, P.B., and Meazell, K. Anomalously Deep Gas Hydrate Stability Zone In Rapidly Formed Sedimentary Basins. Poster presented at the Offshore Technology Conference (OTC). May 2023.
- You, K., Thomas, C., Savage, A., Murphy, Z., O'Connell, J., Flemings, P.B. Dissolved methane diffusion drives hydrate-bearing pressure core degradation during long-term storage in water. Poster presented at International Gas Hydrates Conference (ICGH10). July 2023.
- You, K., Portnov, A., Flemings, P.B. Methane dynamics associated with the thawing subsea permafrost since the Last Glacial maximum. Abstract ID 250. Oral talk presented at International Gas Hydrates Conference (ICGH10). July 2023.
- You, K., Flemings, P.B. and DiCarlo, D. Thermal and Hydraulic Controls on Gas Production from Methane Hydrate Reservoirs. OS21B-1421. Poster presented at the Fall Meeting of the American Geophysical Union. December 2023.