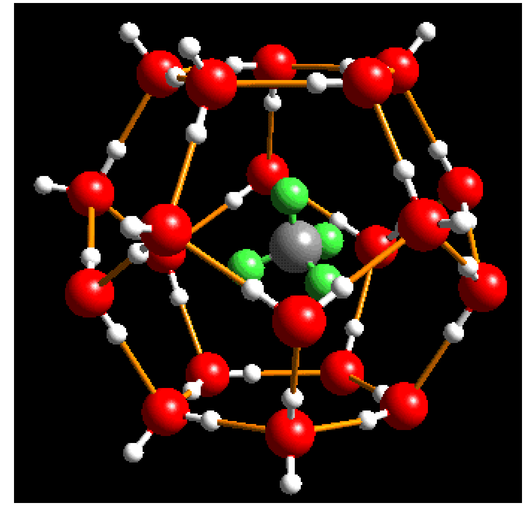
# An Overview of US DOE Gas Hydrate Research and Development

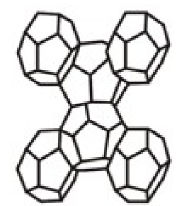
## Midstream Workshop, Houston TX

NATIONAL ENERGY TECHNOLOGY LABORATORY

# What are Gas Hydrates?

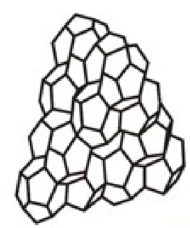
- Crystalline solid consisting of gas molecules, usually methane, each surrounded by a cage of water molecules
  - One volume hydrate typically equivalent to 160-180 volumes methane gas
- Natural gas hydrate (NGH) is an enormous global storehouse of organic carbon.
- Methane is less carbon intensive fuel than other hydrocarbon, 44% less CO2 than coal, 29% less than oil, per unit energy release.
- Methane is 20x stronger global warming gas than $CO_2$





Structure I

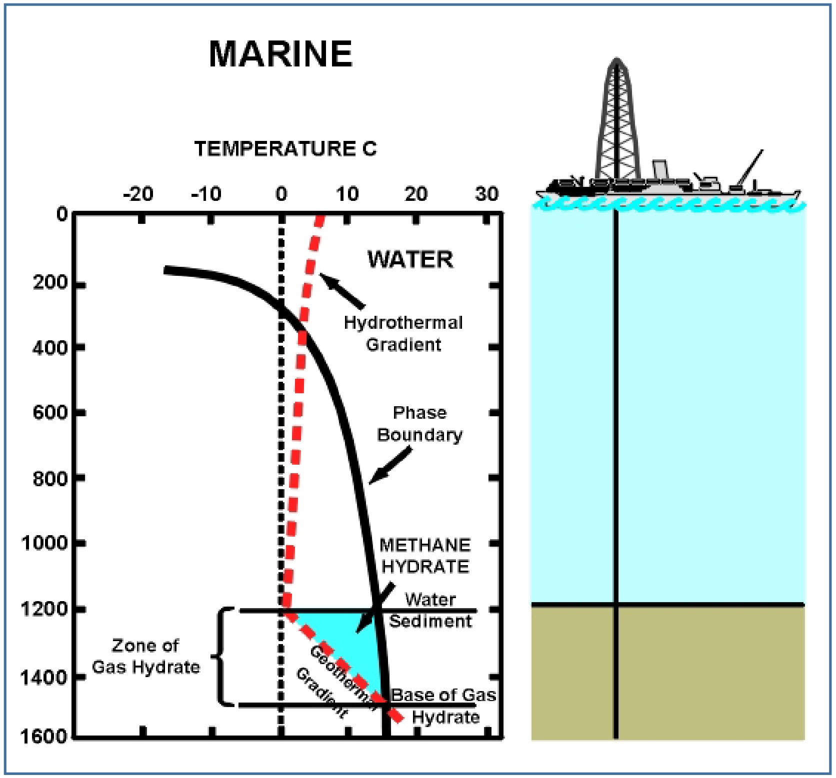
**Methane, ethane, carbon dioxide....**

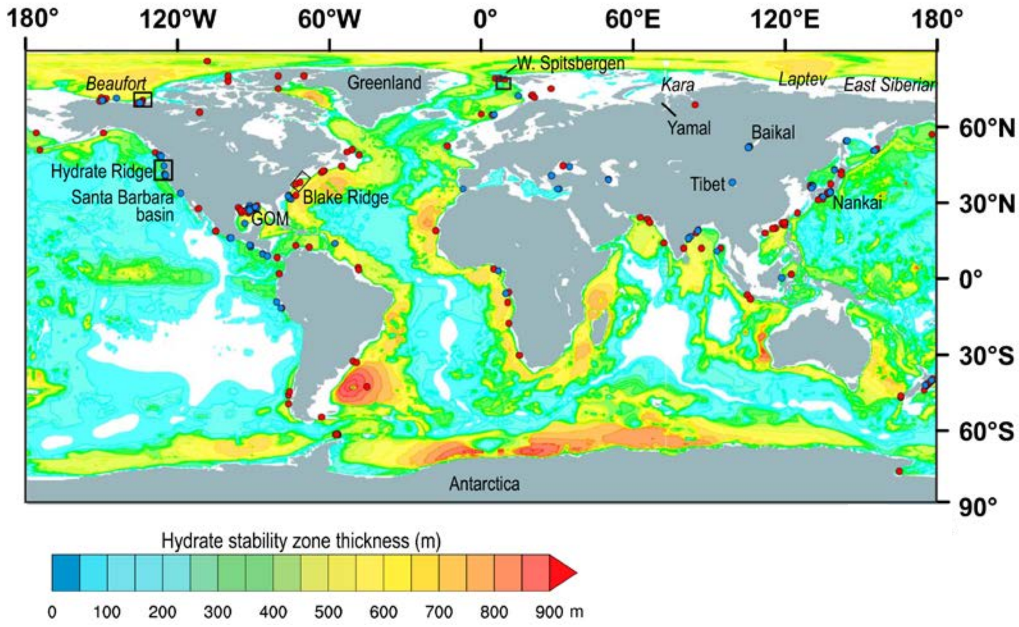


Structure II

**Propane, iso-butane, *natural gas*....**

# Gas Hydrate Stability Conditions




*Ruppel and Kessler, 2017*

# Gas Hydrate Stability Conditions

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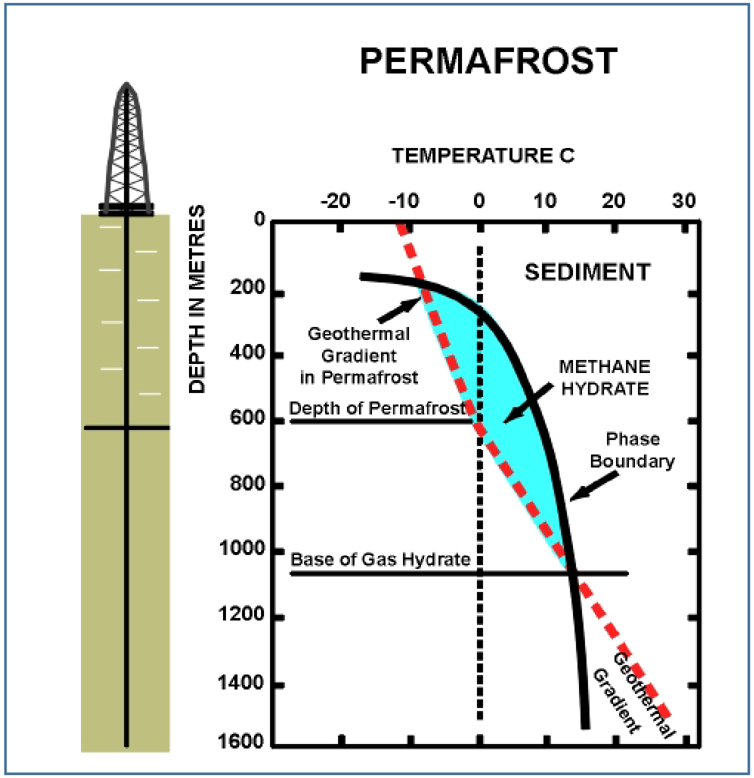



Arctic Permafrost Gas Hydrate Stability Conditions

***Max and Lowrie, 1992***
***Collett et al., 2009***

# Gas Hydrate in Nature

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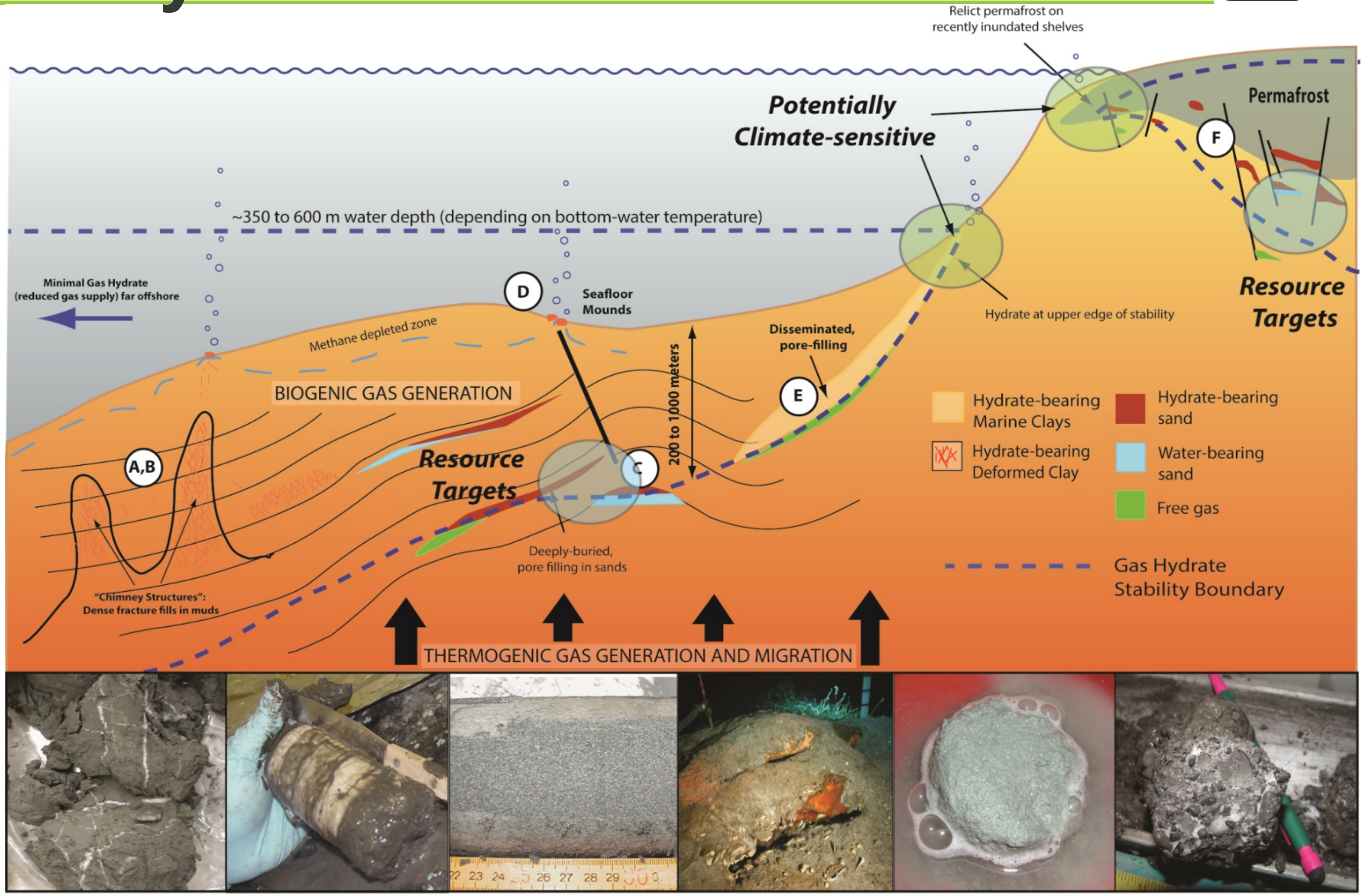
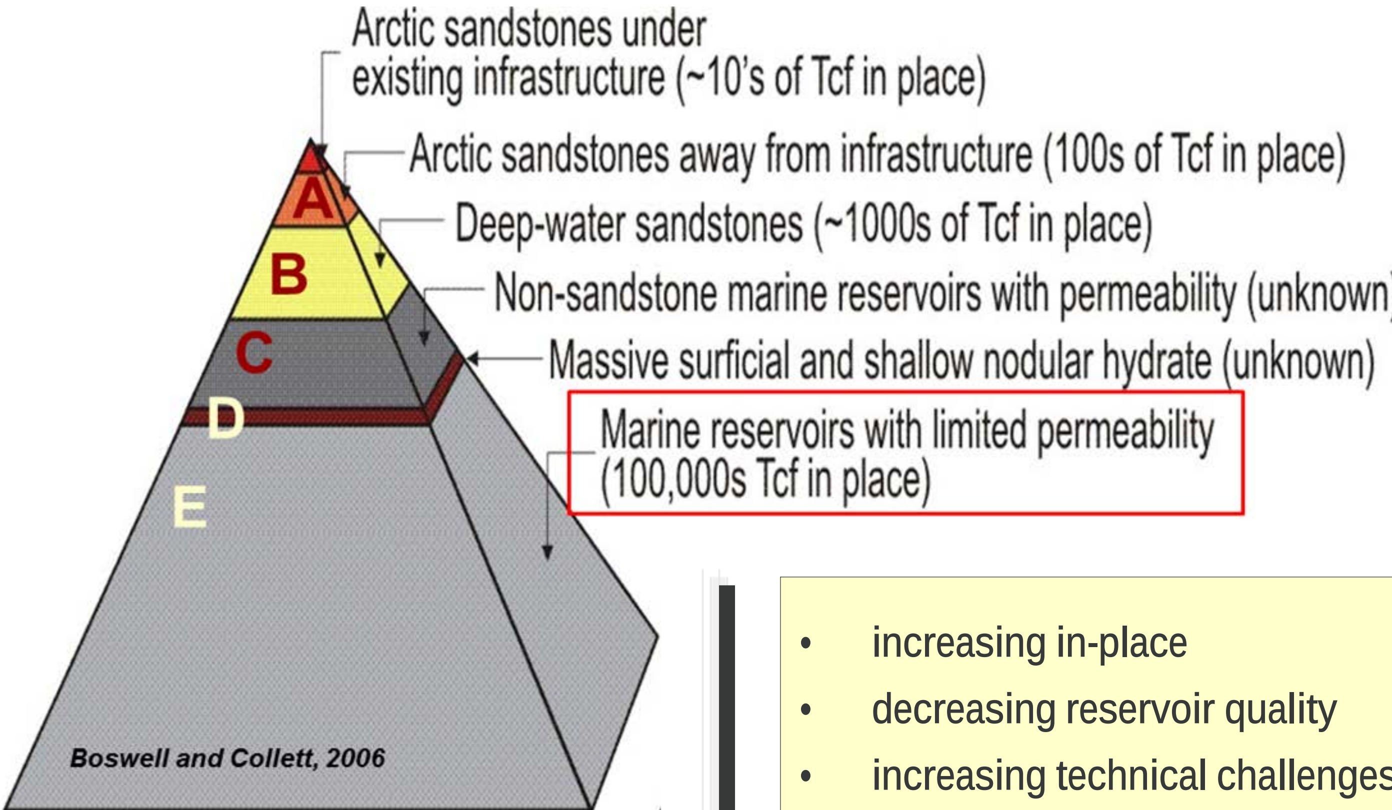



| | | | | | |
|---|---|---|---|---|---|
| Hydrate-filled veins | Massive hydrate lenses | Grain-filling hydrate sands | Massive hydrate sea-floor mounds | Grain-filling hydrate in clays | Grain-filling hydrate in sands |
| A | B | C | D | E | F |

# The Gas Hydrates Resource Pyramid

## *Distribution of huge in-place resource*




*Data Sources*
*A: Collett, 1993; Collett, 1995*
*B: MMS, 2008*
*C: Unassessed (India, Korea expeditions)*
*D: Unassessed*
*E: Collett, 1995*

- increasing in-place
- decreasing reservoir quality
- increasing technical challenges
- decreasing % recoverable

# Alaska North Slope GH Assessment

- **Discrete Accumulations**
  - Petroleum System
  - The USGS method for "conventional" reservoirs
  - Three AUs; with size range and accumulations numbers for each
- **~85 TCF gas in place**
- **Technically Recoverable**
- **Existing Technology**
  - High ultimate tech recoverability

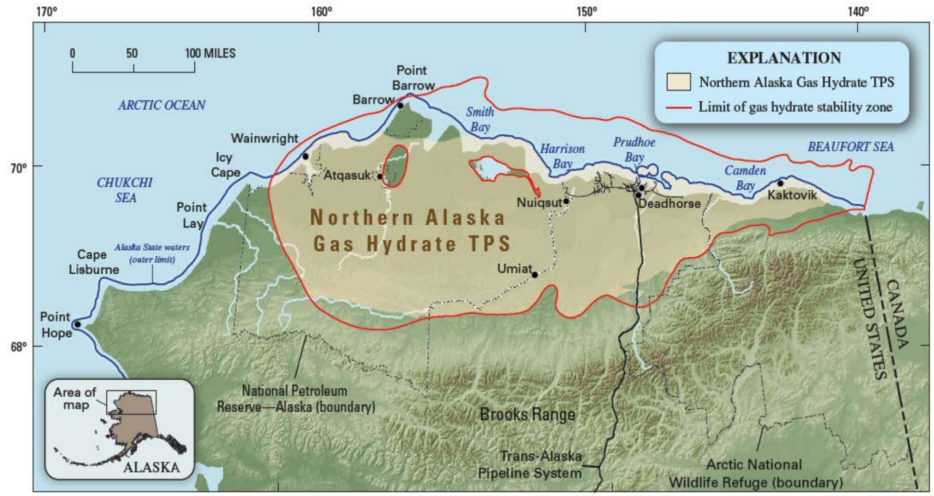
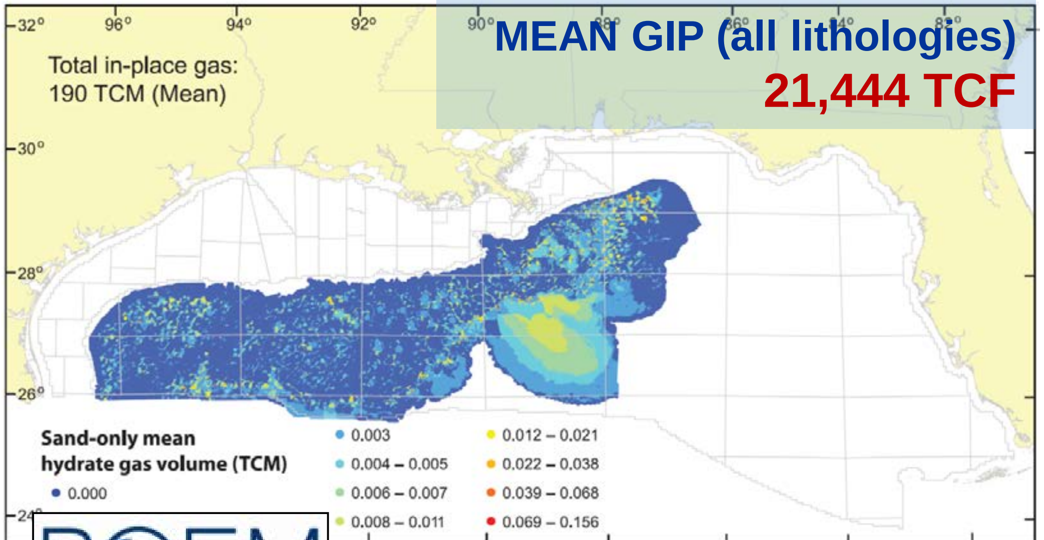


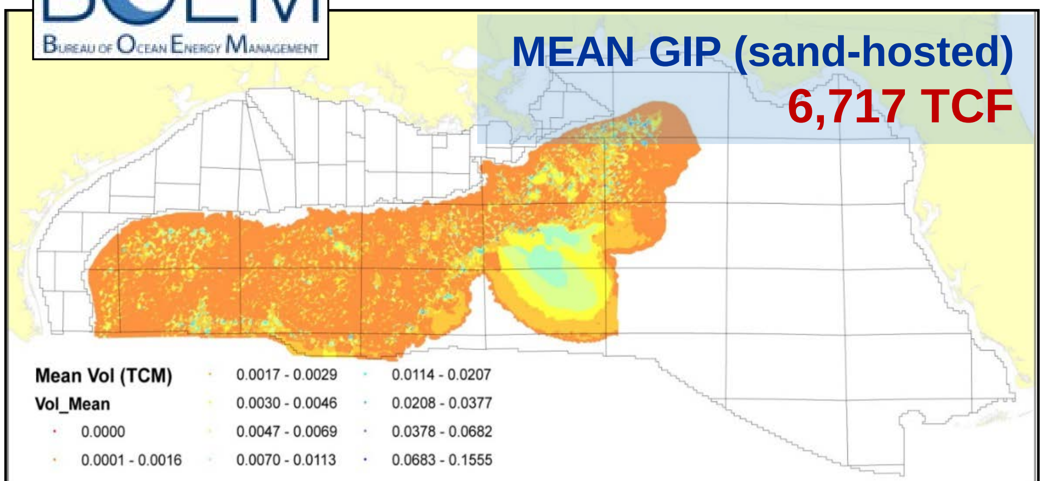

**Table 1.** Alaska North Slope–Gas hydrate assessment results.

[BCFG, billion cubic feet of gas. MMBNGL, million barrels of natural gas liquids. Results shown are fully risked estimates. F95 represents a 95-percent chance of at least the amount tabulated; other fractiles are defined similarly. Fractiles are additive, assuming perfect positive correlations. NGL, natural gas liquids; TPS, total petroleum system; AU, assessment unit.]

| ***Total Petroleum System*** *and Assessment Unit* | Field Type | ***Total Undiscovered Resources*** | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | ***Gas (BCFG)*** | | | | ***NGL (MMBNGL)*** | | | |
| | | F95 | F50 | F5 | Mean | F95 | F50 | F5 | Mean |
| **Northern Alaska Gas Hydrate TPS** | | | | | | | | | |
| Sagavanirktok Formation Gas Hydrate AU | *Gas* | 6,285 | 19,490 | 37,791 | 20,567 | 0 | 0 | 0 | 0 |
| Tuluvak-Schrader Bluff-Prince Creek Formations Gas Hydrate AU | *Gas* | 8,173 | 26,532 | 51,814 | 28,003 | 0 | 0 | 0 | 0 |
| Nanushuk Formation Gas Hydrate AU | *Gas* | 10,775 | 35,008 | 68,226 | 36,857 | 0 | 0 | 0 | 0 |
| **Total Undiscovered Resources** | | **25,233** | **81,030** | **157,831** | **85,427** | **0** | **0** | **0** | **0** |

# In-Place Gas Hydrate in US OCS



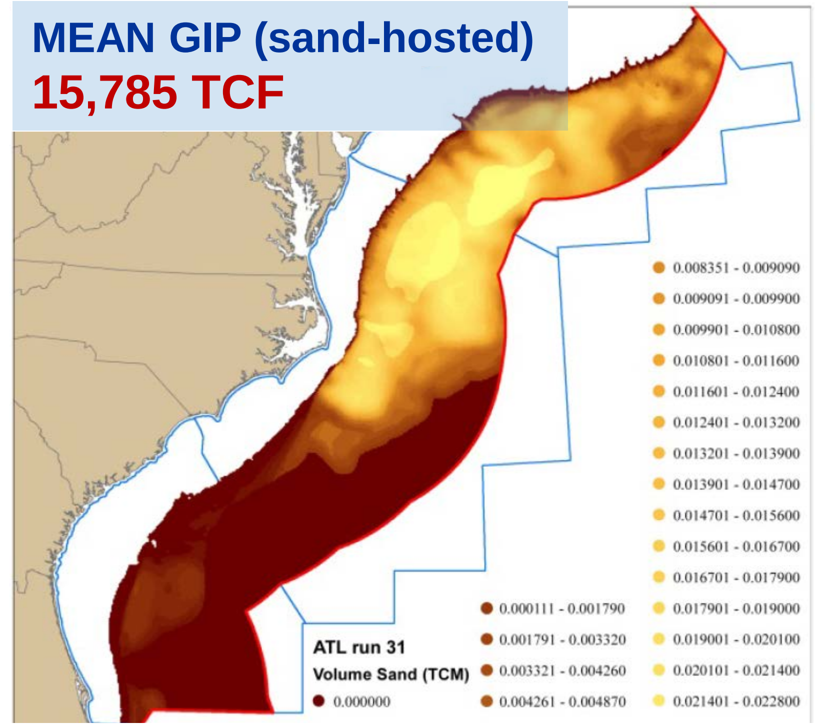




*Table 1. BOEM in-place gas hydrate resource volumes for the Atlantic, Pacific, and Gulf of Mexico Outer Continental Shelf. Units are trillion cubic feet; 1 x 10[12] ft[3]. Resource volumes have not been subject to geologic risk.*

| Region | In-Place Gas Hydrate Resources Gas (Tcfg) | | |
|---|---|---|---|
| | 95% | Mean | 5% |
| Atlantic OCS | 2,056 | 21,702 | 52,401 |
| Pacific OCS | 2,209 | 8,192 | 16,846 |
| Gulf of Mexico OCS | 11,112 | 21,444 | 34,423 |

- BOEM, 2008; 2013

# US National Gas Hydrate Program

NATIONAL ENERGY TECHNOLOGY LABORATORY

### Program Mission

- Determine the potential for methane hydrates as an energy source,
- Determine environmental impacts associated with production, and it's role in the global climate cycle.

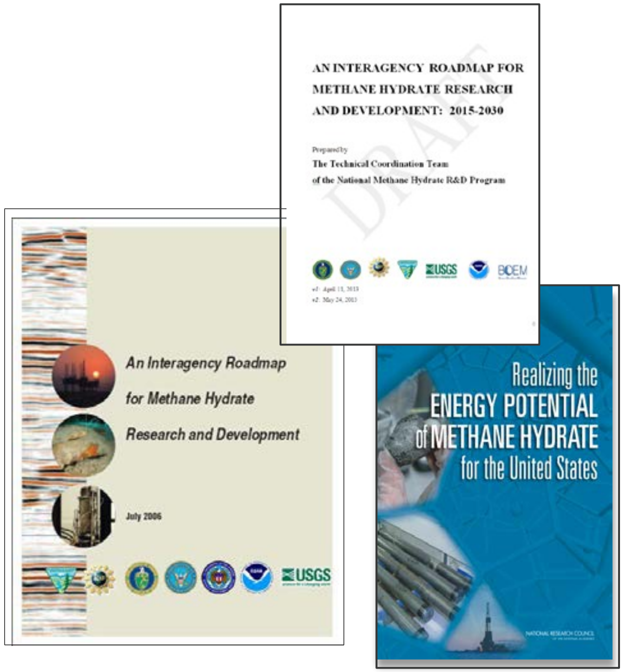
- Interagency & International
- Gas Hydrate In Nature
- Science And Technology
- Outreach & Education
- Emphasis On Research In The Field

## Near-term Goals (2020)

- Demonstrate long-term Technical Recoverability (Alaska)
- Confirm Gulf of Mexico Resource Assessment
- Continue International Collaborations

## Long-term Goals (2025)

- Confirm scale of US resource base (+ Atlantic)
- Demonstrate Production Approach (Alaska + International)
- Develop consensus view on GH/Climate linkages via field programs + modeling



# DOE – NETL GH Program

## Major Program Areas

### Marine Resource Characterization / Confirmation

- Marine drilling and coring programs throughout US OCS
- Focus on major drilling/logging/coring field effort in GoM with UT

### Production Science

- Evaluating behavior of GH in response to induced change
- Focus on establishment of long term GH production test in AK

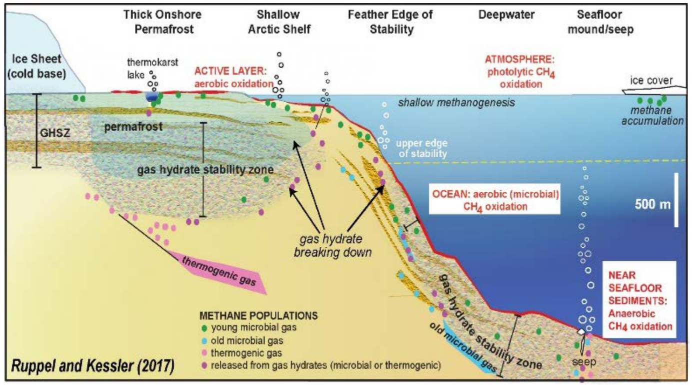
### Fundamental Science

- Fundamental scientific efforts in geophysics, experimentation, simulation, tool development and other areas to support scientific understanding necessary for resource characterization, exploration and production of GH
- Conducted with Academia, National Labs and other Federal Agencies

### GH Role in the Natural Environment

- Investigate, through the acquisition of field data and development of predictive models, the nature of hydrate response to warming climates and implications for ocean and atmospheric chemistry.
- Conducted with Academia, National Labs and other Federal Agencies

### International Collaborations



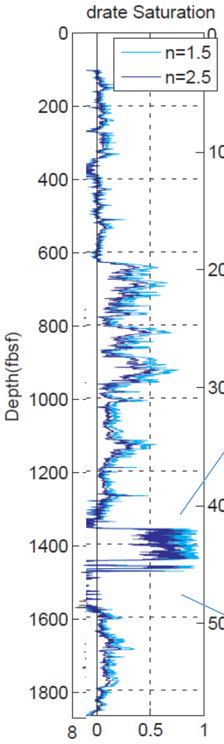

# GOM² Expedition: UT Austin

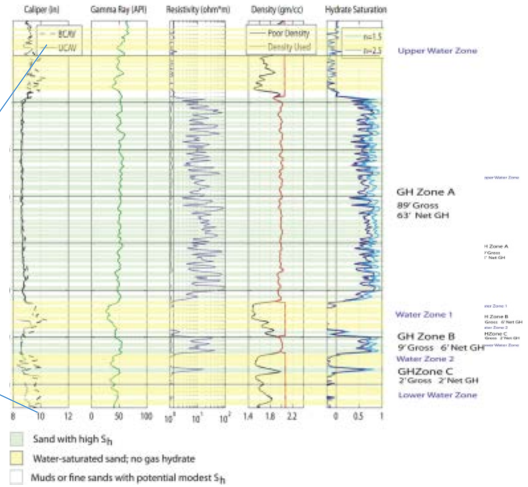
Pressure-coring at known sites and exploration of high-value new sites

## Expedition – 1 (Completed Spring 2017)

- Single site, two-hole, test of pressure corer, core transfer and core analysis. 20 deployments.
- Full science program (UT, DOE-NETL, USGS, Geotek)
- Two bit configurations (PCTB) tested: (PCTB-CS: 6% Rec., PCTB-FB: New tool design: 75% Rec)
- <u>All 20 sample transfer vessels filled with very high-quality hydrate-bearing sand samples</u>
- **NO SAFETY INCIDENTS, NO WELL CONTROL INCIDENTS, ON TIME, ON BUDGET**
- Core to undergo analysis by multiple research groups: UT, USGS, NETL, AIST

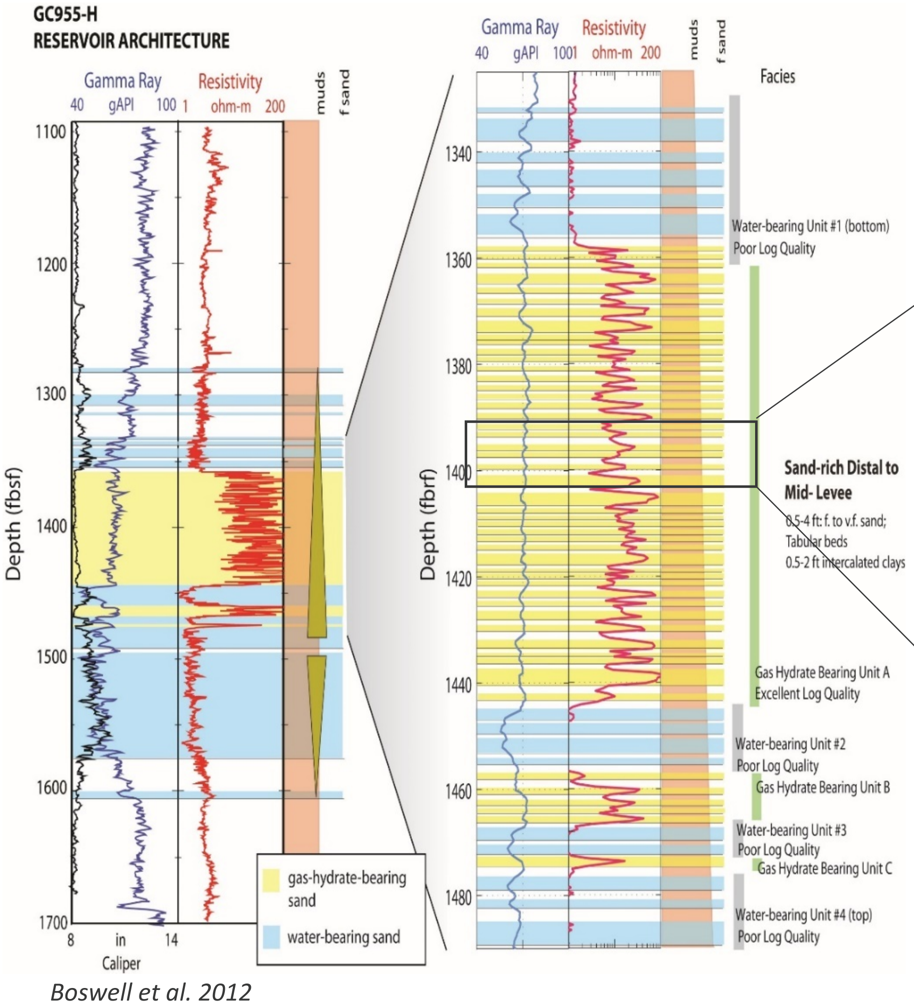

*Helix Q4000 (exp-1)*

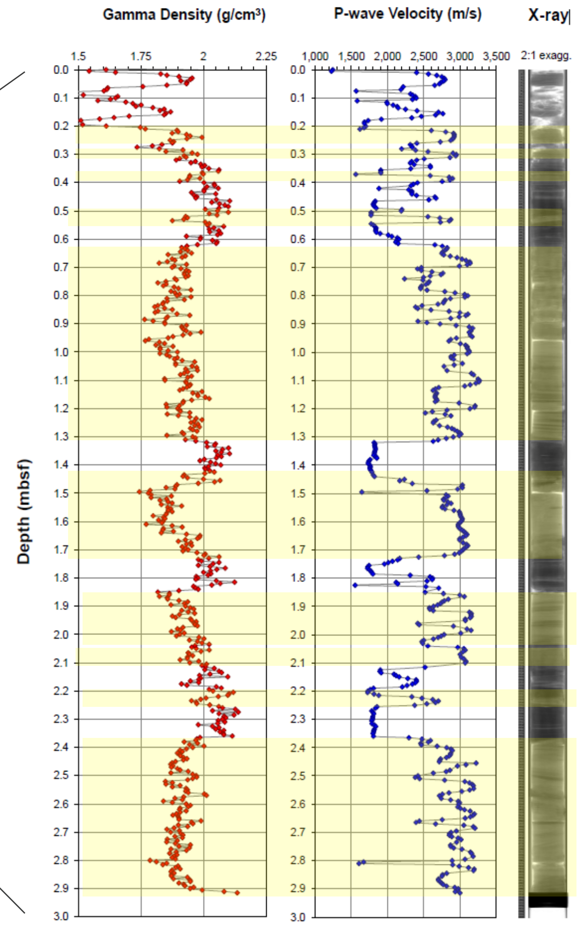



# Green Canyon 955

Reservoir Architecture confirmed at Core Scale

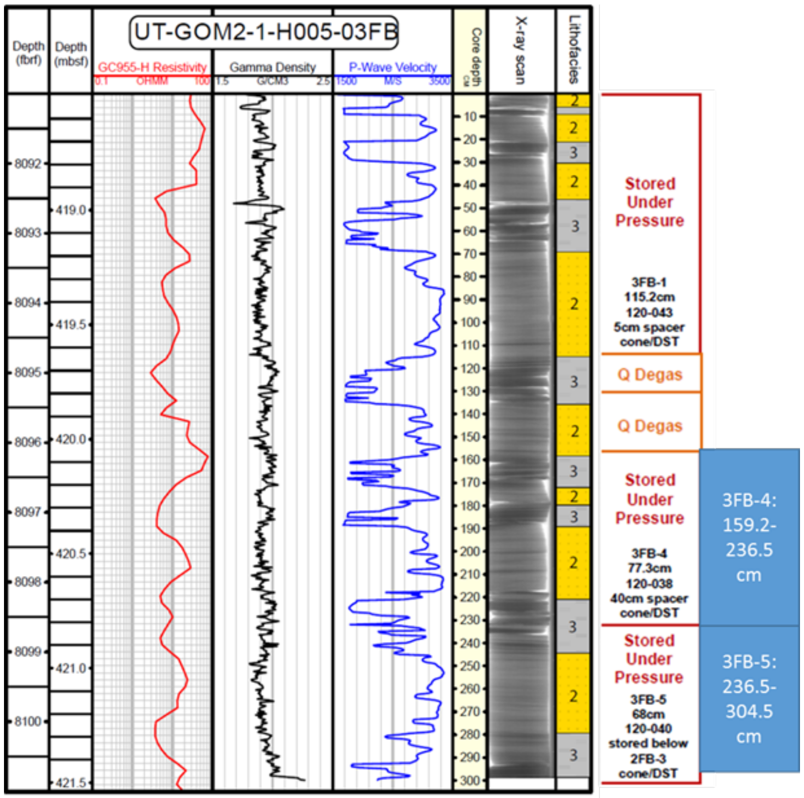



*Boswell et al. 2012*



# Expedition-1:  Post Expedition Science

**P**ressure **C**ore **C**haracterization **T**ools (US); NETL Laboratories

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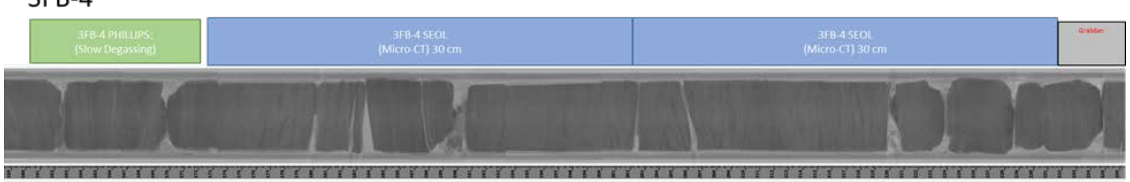



### Full Characterization of Pressure Cores

- Index-level Properties: grain size, porosity, Sh
- Hydraulic-Mechanical Properties:
  - Consolidation, volume compressibility, Vertical/horizontal permeability, acoustic wave velocity, modulus, strength, water retention curve
- High Resolution Visualization of hydrate pore habits

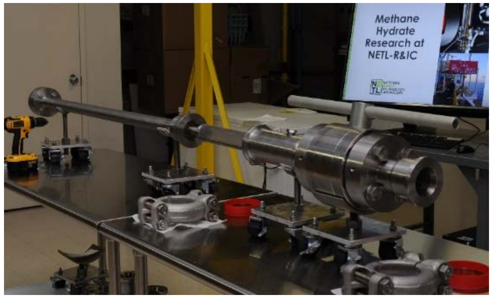
### Pressure Core Characterization Tools

- Retrieve, transfer, cut, subcore, and characterize naturally-occurring hydrate-bearing sediments at *in situ* P/T conditions

# Pressure Core Characterization Tools

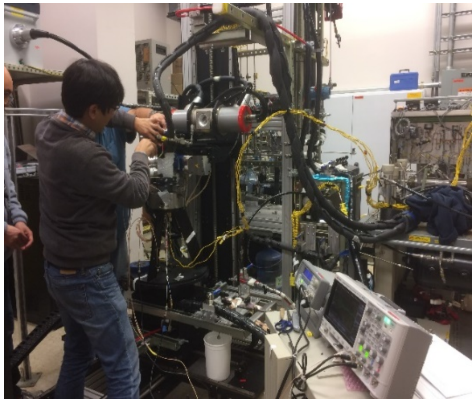
Transport Chamber

Manipulator w/ temporary storage chamber

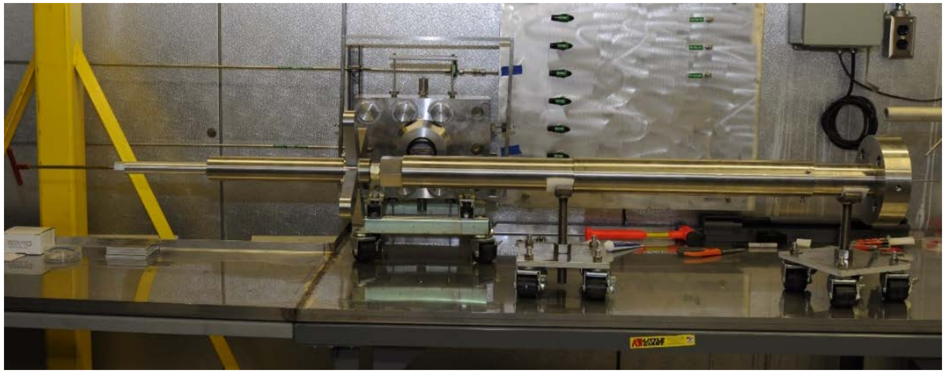



CT scanning chamber

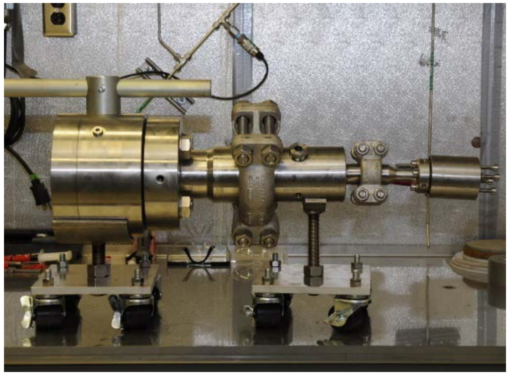
Cutter



Effective Stress Chamber



Sub-coring tool

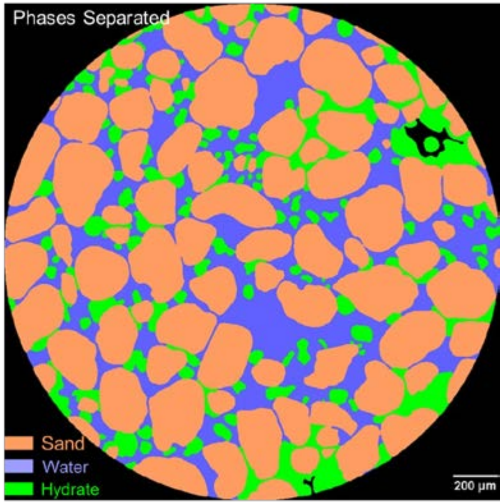


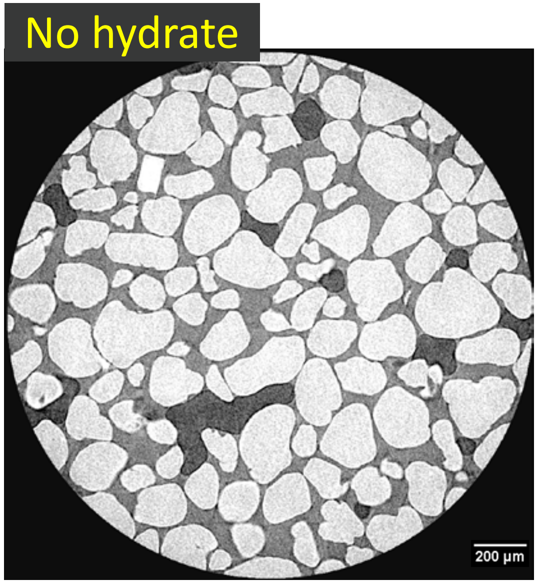
Sub-corer Transfer Assembly

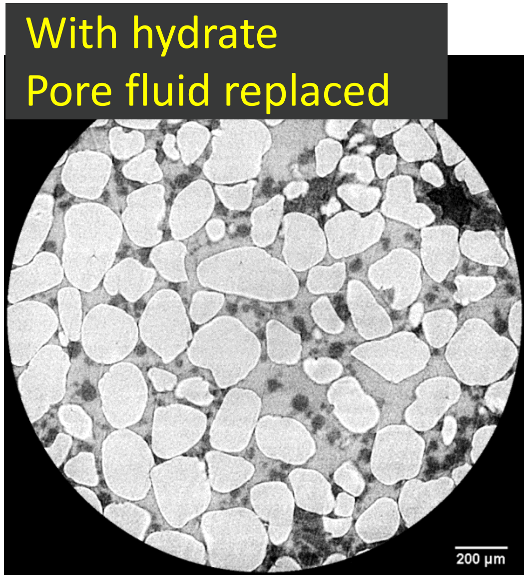
# Visualization of Hydrate Pore Habit

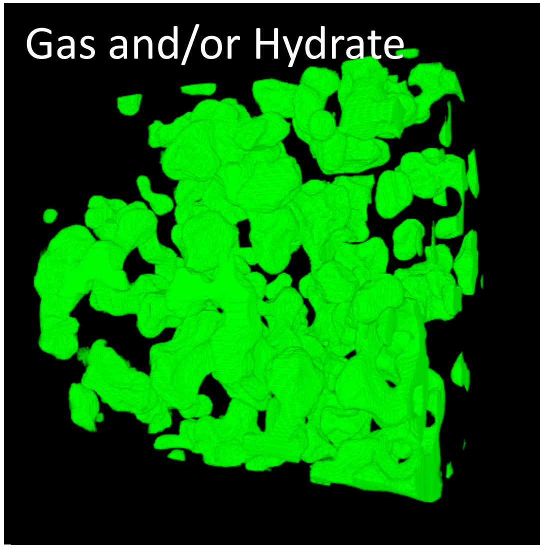
(a)


- Non-destructive CT imaging
- High resolution (1μm)
- Phase separation in 3D reconstructed images
- Further physical properties analyses



# GOM$^2$ Expedition: UT Austin

Pressure-coring at known sites and exploration of high-value new sites

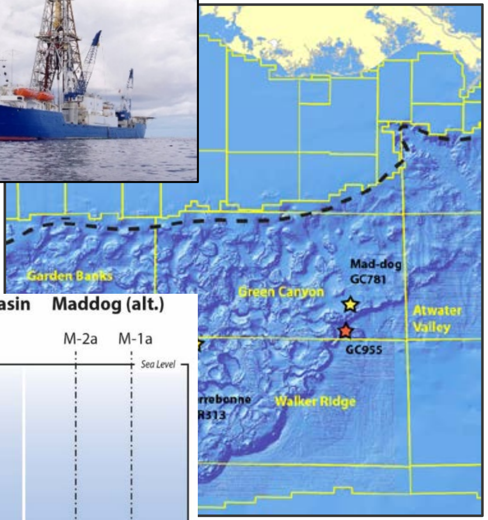
## Expedition – 2 (2020)

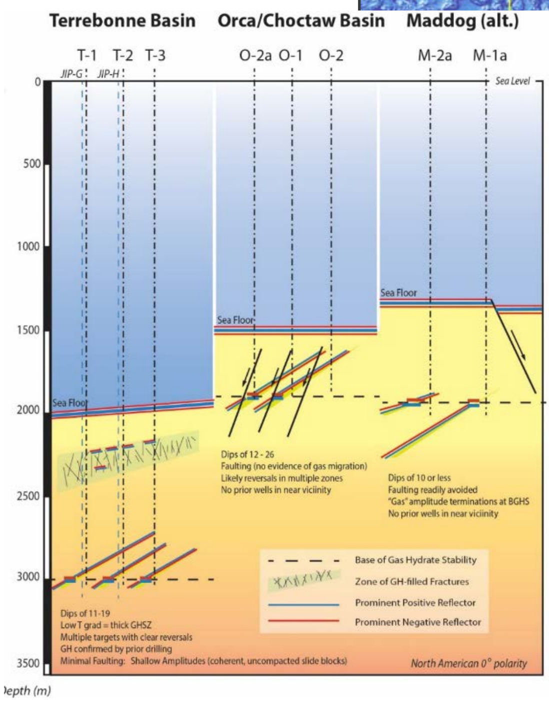
- Logging, MDT, and pressure coring at multiple sites.
- Scheduled for FY20 from *Joides Resolution* as IODP CPP 386 (approved by IODP May 2017), collaboration with IODP, TAMU, and the NSF.
- ~60 days of ship time
- Conducted within the IODP structure:
  - Access to world's premier scientific drilling vessel
  - IODP cost contribution, staffing, and liability coverage
  - IODP scientific and safety reviews/approvals

## Core twins of 2009 JIP WR313 G&H Holes

- Gas and fluid chemistry; GH Habit; Microbiology
- Reservoir and Seal Petrophysics

*Joides Resolution (Exp-2)*



# Alaska Long Term Production Test

## Goals

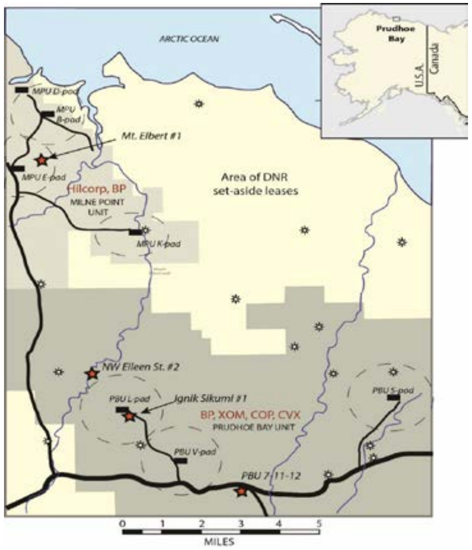
- Understand behavior of GH system in response to induced change over prolonged period (6 mo. Minimum)
- Evaluate technologies and approaches for initiating and maintaining flow

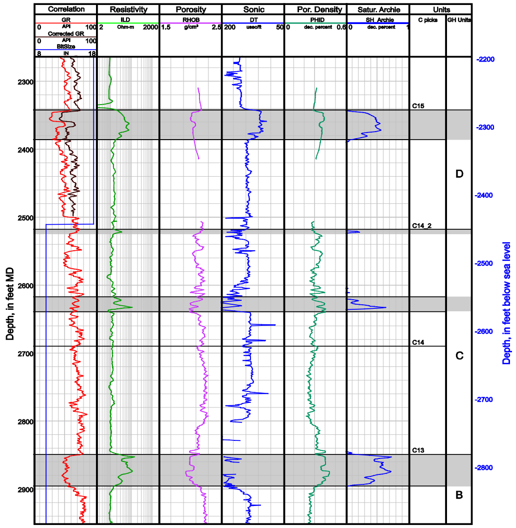
## Alaska North Slope represents ideal test bed:

- Geologically well-characterized (complimented as needed by project strat/sci test wells)
- Hydraulic isolation (away from sources of free gas or water)
- Sufficient reservoir temperature (at least 5C) and intrinsic reservoir quality
- Multiple reservoir zones – operational risk mitigation and expanded science options
- Well location that allows continual operations of 6 mo (minimum); optimally18-24 mo.
- Location that minimizes interference with ongoing operations
- Non-disruptive gas/water handling
- Minimal complexity – avoid use of unproven technologies

## Key Test components

- Depressurization – pre-set or steady rates – enable scale to commercial
- Flow assurance - ability to maintain wellbore during likely interruptions
- Sand control
- Progressive well stimulation available – thermal, mechanical, chemical



# Field Program Planning

## Three Wells and Two Phase Program

- Phase 1: Conduct stratigraphic test and complete as monitoring well
- Phase 2: Establish facilities; drill & instrument science well; drill, complete and conduct test in production test well

## Stratigraphic Test Well

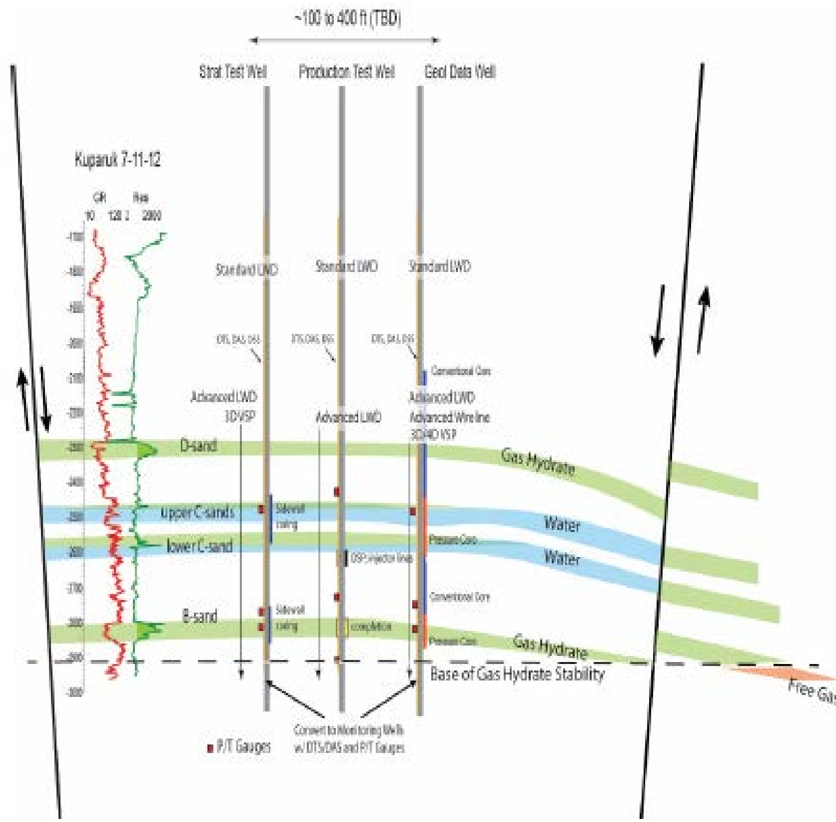
- To Confirm state of GH a Site
- To allow selection of test zone and finalization of scienc well and production  well completion design
- Goal is fully saturated GH in B sand
- Fall-back is fully saturated D sand.

## Geo-Data Well

- To acquire all geologic, engineering, petrophysical data needed to characterize the test reservoir and effectivel interpret test results

## Production Test Well

- Completed for production and monitoring over extended period
- Sand control completion
- Well intervention pre-positioned



# Geologic Input Models: B-sand

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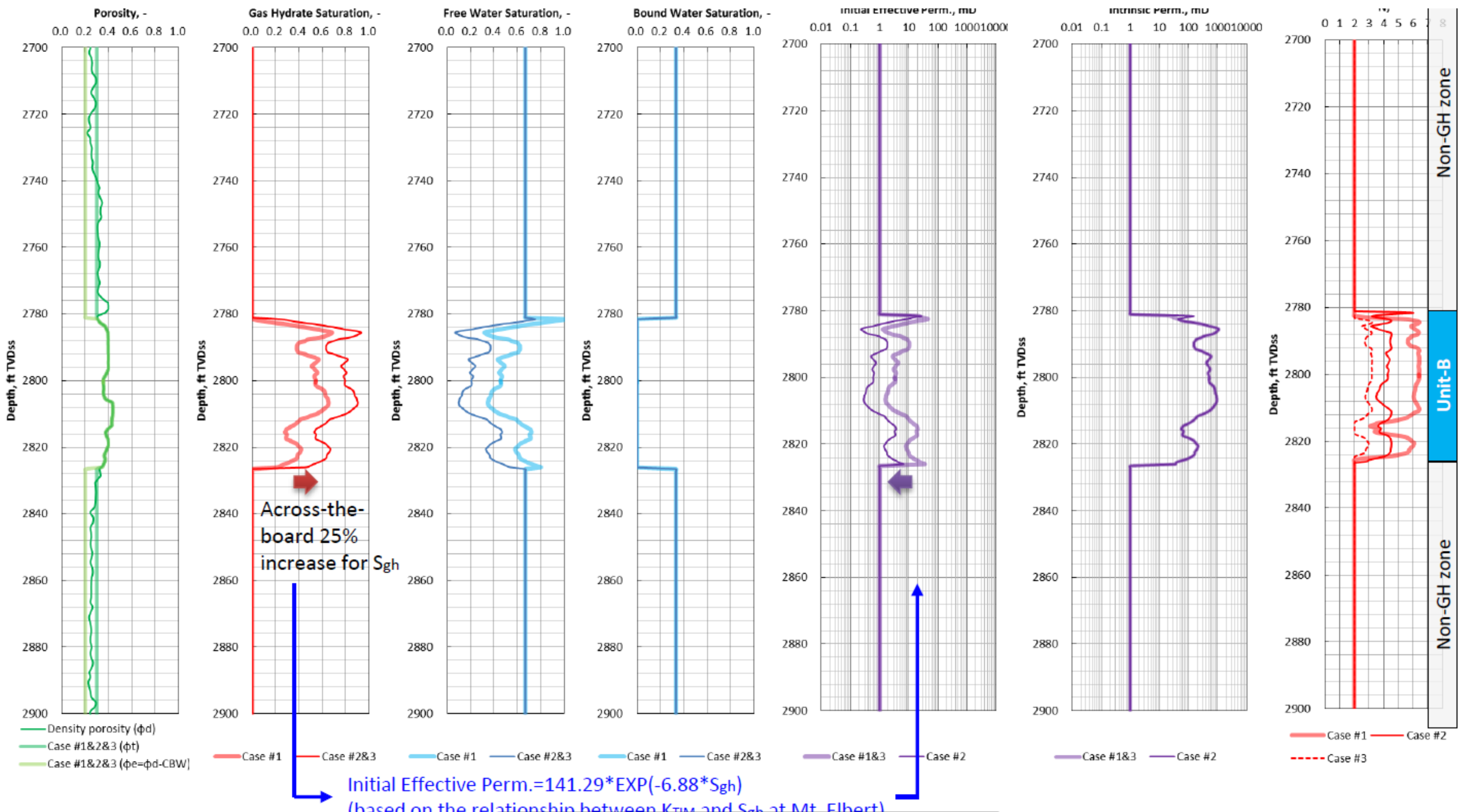
JOGMEC Simulation Input Summary




For further details of Case #1 (original model), s der Meeting on December, 16th 2015.
Filename: 151216_7-11-12 Reservoir Model Construction.pptx

5

# Geologic Input Model: B-sand

## Comparison of JOGMEC and NETL Approaches

**Gridding:** Similar; NETL coarser vertically; NETL mesh sensitivity analysis performed to ensure production consistency

**Lateral boundaries:** Not relevant

**Porosity, P, T, $K_{intrinsic}$, etc.:** Similar

**FBHP:** Similar

**Shale:** JOGMEC impermeable; NETL permeable

**Saturation:**

- JOGMEC Cases 2, 3: 55% to 85% (Assumes Log is Wrong)
- JOGMEC Case #1: 30% to 65% (Assumes log is correct)
- NETL: vertical heterogeneity

**Bound v. Free Water:**

- JOGMEC: Bound water = 0%
- NETL: Bound water 7 – 23%

**Initial Effective Permeability:**

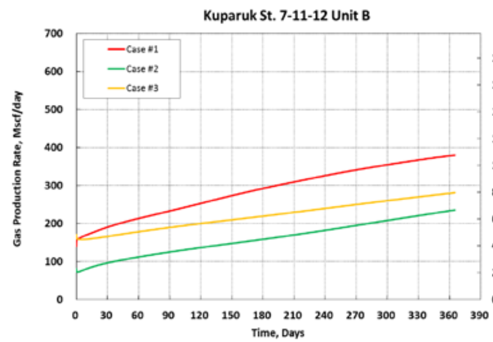
- JOGMEC Case 1, 3: 1 to 20 md
- JOGMEC Case 2: 0.3 to 3 md
- NETL Case 1: 0.1 md fixed
- NETL Case 2: 1.0 md fixed
- NETL Case 3: 10.0 md fixed

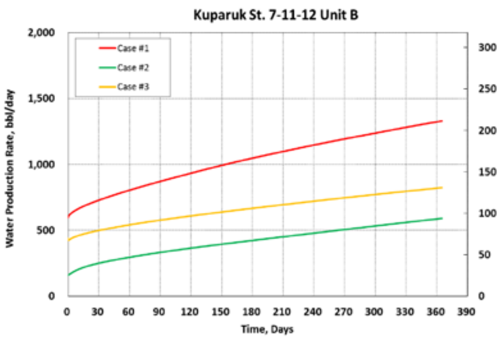
| B-sand model input | | | | | | 3 cases | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Top (ft) | H (ft) | Por | Sgh | Swfree | Swirr | Kinit | Kinit | Kinit | Kintr | N |
| 2782 | 2 | 0.37 | 0.75 | 0.10 | 0.15 | 0.10 | 1.00 | 10.00 | 400.00 | |
| 2784 | 2 | 0.40 | 0.80 | 0.08 | 0.12 | 0.10 | 1.00 | 10.00 | 500.00 | |
| 2786 | 2 | 0.40 | 0.80 | 0.08 | 0.12 | 0.10 | 1.00 | 10.00 | 500.00 | |
| 2788 | 2 | 0.40 | 0.65 | 0.12 | 0.23 | 0.10 | 1.00 | 10.00 | 300.00 | |
| 2790 | 2 | 0.40 | 0.65 | 0.15 | 0.20 | 0.10 | 1.00 | 10.00 | 300.00 | |
| 2792 | 2 | 0.40 | 0.80 | 0.12 | 0.08 | 0.10 | 1.00 | 10.00 | 500.00 | |
| 2794 | 2 | 0.40 | 0.75 | 0.10 | 0.15 | 0.10 | 1.00 | 10.00 | 400.00 | |
| 2796 | 2 | 0.40 | 0.80 | 0.09 | 0.11 | 0.10 | 1.00 | 10.00 | 500.00 | |
| 2798 | 2 | 0.39 | 0.75 | 0.10 | 0.15 | 0.10 | 1.00 | 10.00 | 400.00 | |
| 2800 | 2 | 0.38 | 0.80 | 0.09 | 0.11 | 0.10 | 1.00 | 10.00 | 500.00 | |
| 2802 | 2 | 0.38 | 0.85 | 0.08 | 0.07 | 0.10 | 1.00 | 10.00 | 700.00 | |
| 2804 | 2 | 0.39 | 0.85 | 0.08 | 0.07 | 0.10 | 1.00 | 10.00 | 700.00 | |
| 2806 | 2 | 0.42 | 0.85 | 0.08 | 0.07 | 0.10 | 1.00 | 10.00 | 700.00 | |
| 2808 | 2 | 0.42 | 0.80 | 0.09 | 0.11 | 0.10 | 1.00 | 10.00 | 500.00 | |
| 2810 | 2 | 0.41 | 0.75 | 0.12 | 0.13 | 0.10 | 1.00 | 10.00 | 400.00 | |
| 2812 | 2 | 0.41 | 0.60 | 0.12 | 0.28 | 0.10 | 1.00 | 10.00 | 200.00 | |
| 2814 | 2 | 0.40 | 0.55 | 0.14 | 0.31 | 0.10 | 1.00 | 10.00 | 100.00 | |
| 2816 | 2 | 0.39 | 0.55 | 0.14 | 0.31 | 0.10 | 1.00 | 10.00 | 100.00 | |
| 2818 | 2 | 0.30 | 0.70 | 0.12 | 0.18 | 0.10 | 1.00 | 10.00 | 400.00 | |
| 2820 | 2 | 0.39 | 0.80 | 0.11 | 0.09 | 0.10 | 1.00 | 10.00 | 500.00 | |
| 2822 | 2 | 0.38 | 0.70 | 0.12 | 0.18 | 0.10 | 1.00 | 10.00 | 400.00 | |
| 2824 | 2 | 0.38 | 0.55 | 0.11 | 0.34 | 0.10 | 1.00 | 10.00 | 100.00 | |

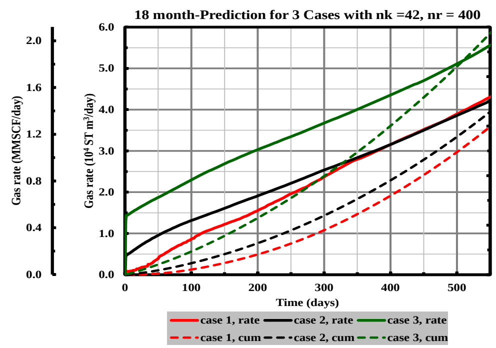
# Comparison Results: Gas Rate/Water Rate

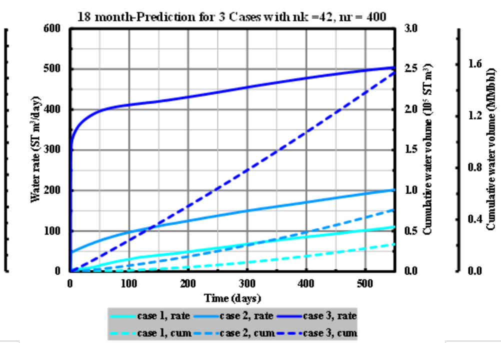
**Code Comparison:**

- Difference on gas/water rate predictions.
- Comparing initial/boundary condition, mesh, relative permeability functions, thermal conductivity, pore compressibility
- Main gap maybe resulting from relative permeability functions (B&C vs. Masuda)
- No laboratory/field data to directly estimate parameters for relative permeability functions
- Progress on developing common conditions and parameter sets to share
- Agreed gas/water flow rates to be used for planning test design and operation



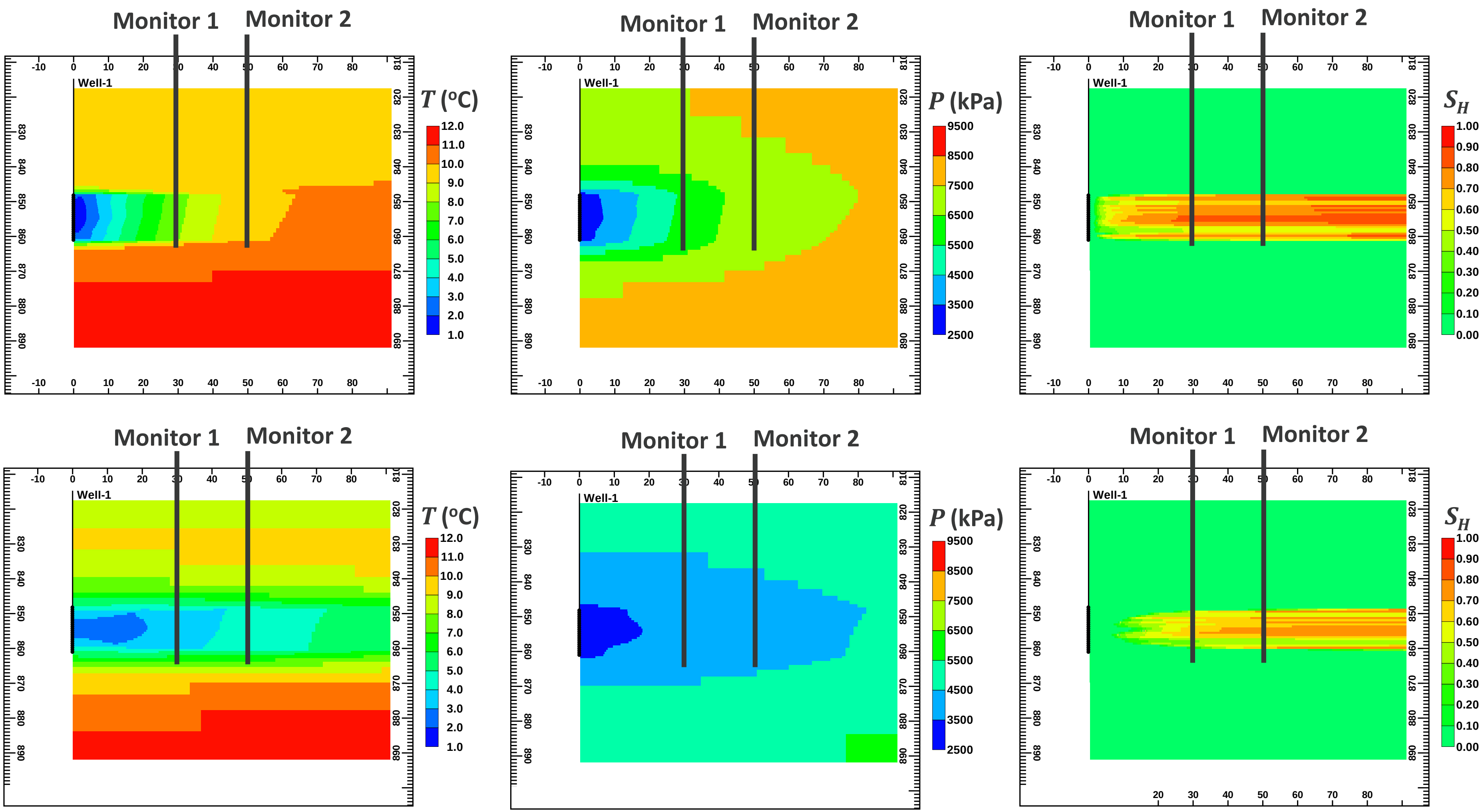




| GAS RATE (mcf/d) | 30 days | 180 days | 360 days |
|---|---|---|---|
| JOGMEC | 100-200 | 160-290 | 220 |
| NETL | 50-600 | 450-1000 | 1000-1400 |
| WATER RATE (bbl/d) | 30 days | 180 days | 360 days |
| JOGMEC | 250-750 | 450-1050 | 600-1350 |
| NETL | 54-2390 | 285-2683 | 502-2957 |

# Evolution of Reservoir Properties (Case 3)

NATIONAL ENERGY TECHNOLOGY LABORATORY

Distribution of Temperature, Pressure and Hydrate Saturation Distribution at 30 /180days



# Code Comparison Study


- 5 Countries
- 21 Institutions
- 12 Codes

# Code Comparison Study

NATIONAL ENERGY TECHNOLOGY LABORATORY

- Objective of Code Comparison Study:
  - Check modeling concepts and approaches on newer hydrate reservoir simulators
  - Compare fundamental capabilities of codes, specific processes or models with properly designed problem sets
  - Share new ideas and approaches
  - Link experiments, field tests, and modeling
- New Focus on IGHCCS2
  - modeling **coupled** thermal, hydrological, and geomechanical processes and the effects on the production

Problem Set to be solved..

↓

- Hydrate Dissociation from IGHCC1 Problems
- Terzaghi's Problem with Hydrate Dissociation
- Nankai Trough Hydrate Production
- Coupled Geomechanics with Radial Flow Problems

↓

More to come.....

# NETL R&IC Gas Hydrate R&D

- Enabling the realization of the Nation's methane hydrates resource potential, through:
  - Improved understanding of the fundamental behavior of hydrates, both *in situ*, and during man-made disturbances.
  - Development of predictive modeling codes that accurately describe gas production, responsive ground deformation, and environmental impacts.
  - Laboratory characterizations that support numerical simulations by providing accurate input data on physical properties of hydrate.