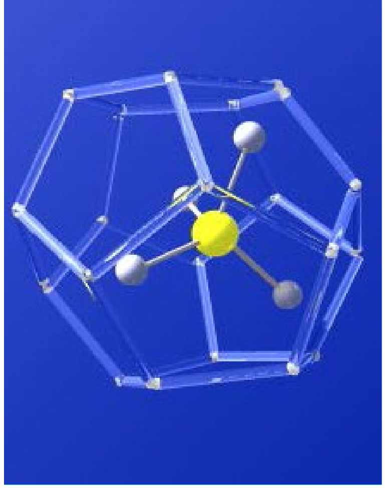
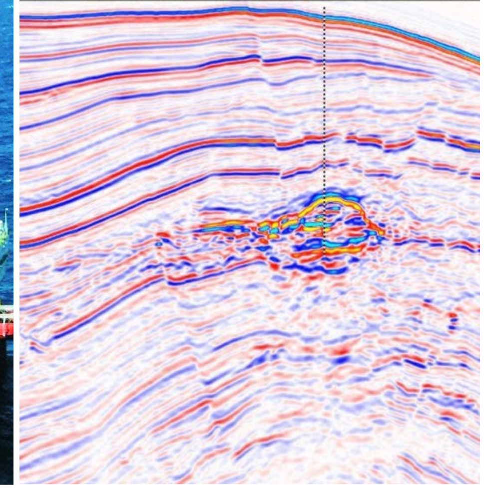



Why Not Gas Hydrates?

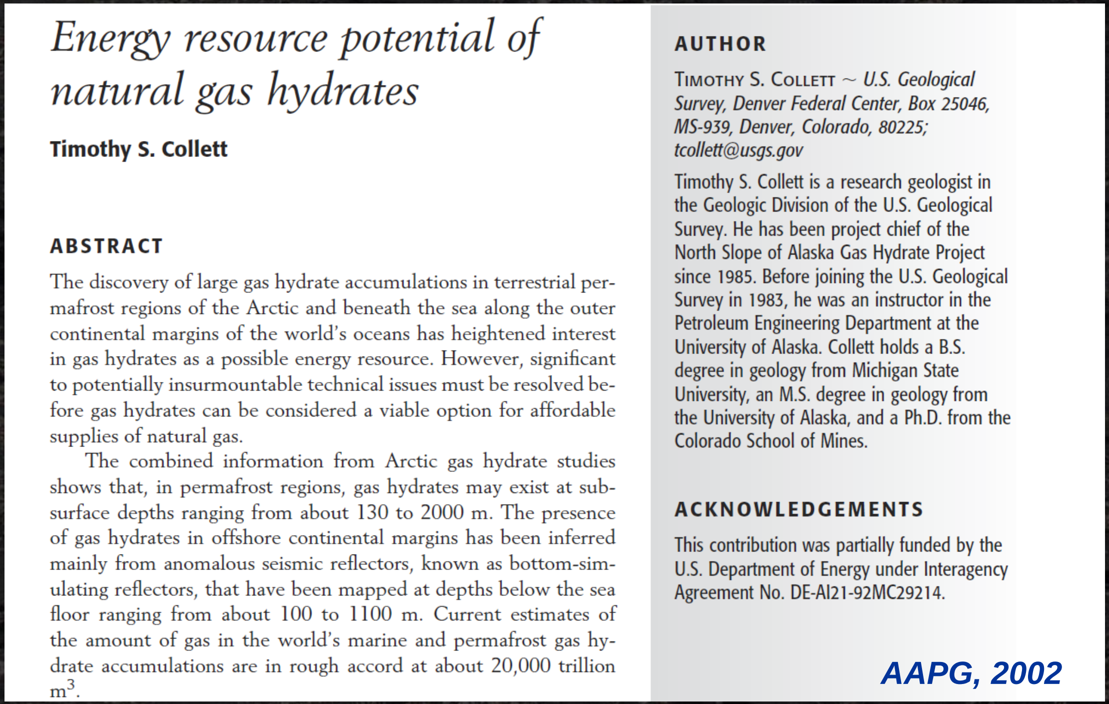
The Evolution of Gas Hydrate from a Gas Resource to a Gas Reserve

Timothy S. Collett
U.S. Geological Survey
Colorado School of Mines

9th International Conference on Gas Hydrates
June 25 - 30, 2017 • Denver, Colorado USA

Presentation Objective

The primary objective of this presentation is to review the geologic, engineering, and "motivational" issues controlling the ultimate commercial production of gas hydrates.



Energy resource potential of natural gas hydrates

Timothy S. Collett

ABSTRACT

The discovery of large gas hydrate accumulations in terrestrial permafrost regions of the Arctic and beneath the sea along the outer continental margins of the world's oceans has heightened interest in gas hydrates as a possible energy resource. However, significant to potentially insurmountable technical issues must be resolved before gas hydrates can be considered a viable option for affordable supplies of natural gas.

The combined information from Arctic gas hydrate studies shows that, in permafrost regions, gas hydrates may exist at subsurface depths ranging from about 130 to 2000 m. The presence of gas hydrates in offshore continental margins has been inferred mainly from anomalous seismic reflectors, known as bottom-simulating reflectors, that have been mapped at depths below the sea floor ranging from about 100 to 1100 m. Current estimates of the amount of gas in the world's marine and permafrost gas hydrate accumulations are in rough accord at about 20,000 trillion m^3.

AUTHOR

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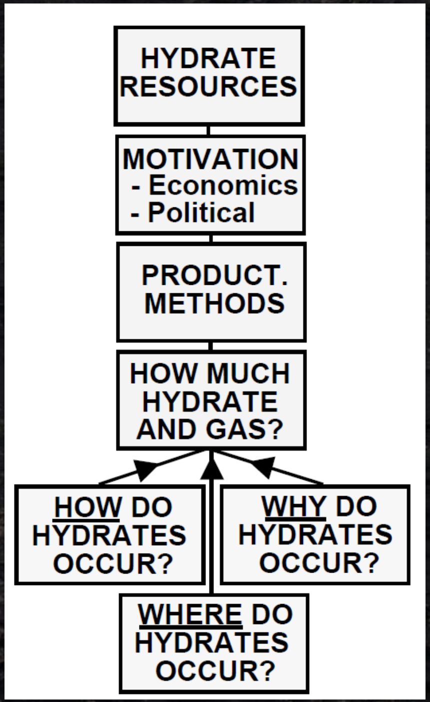
Timothy S. Collett is a research geologist in the Geologic Division of the U.S. Geological Survey. He has been project chief of the North Slope of Alaska Gas Hydrate Project since 1985. Before joining the U.S. Geological Survey in 1983, he was an instructor in the Petroleum Engineering Department at the University of Alaska. Collett holds a B.S. degree in geology from Michigan State University, an M.S. degree in geology from the University of Alaska, and a Ph.D. from the Colorado School of Mines.

ACKNOWLEDGEMENTS

This contribution was partially funded by the U.S. Department of Energy under Interagency Agreement No. DE-AI21-92MC29214.

AAPG, 2002

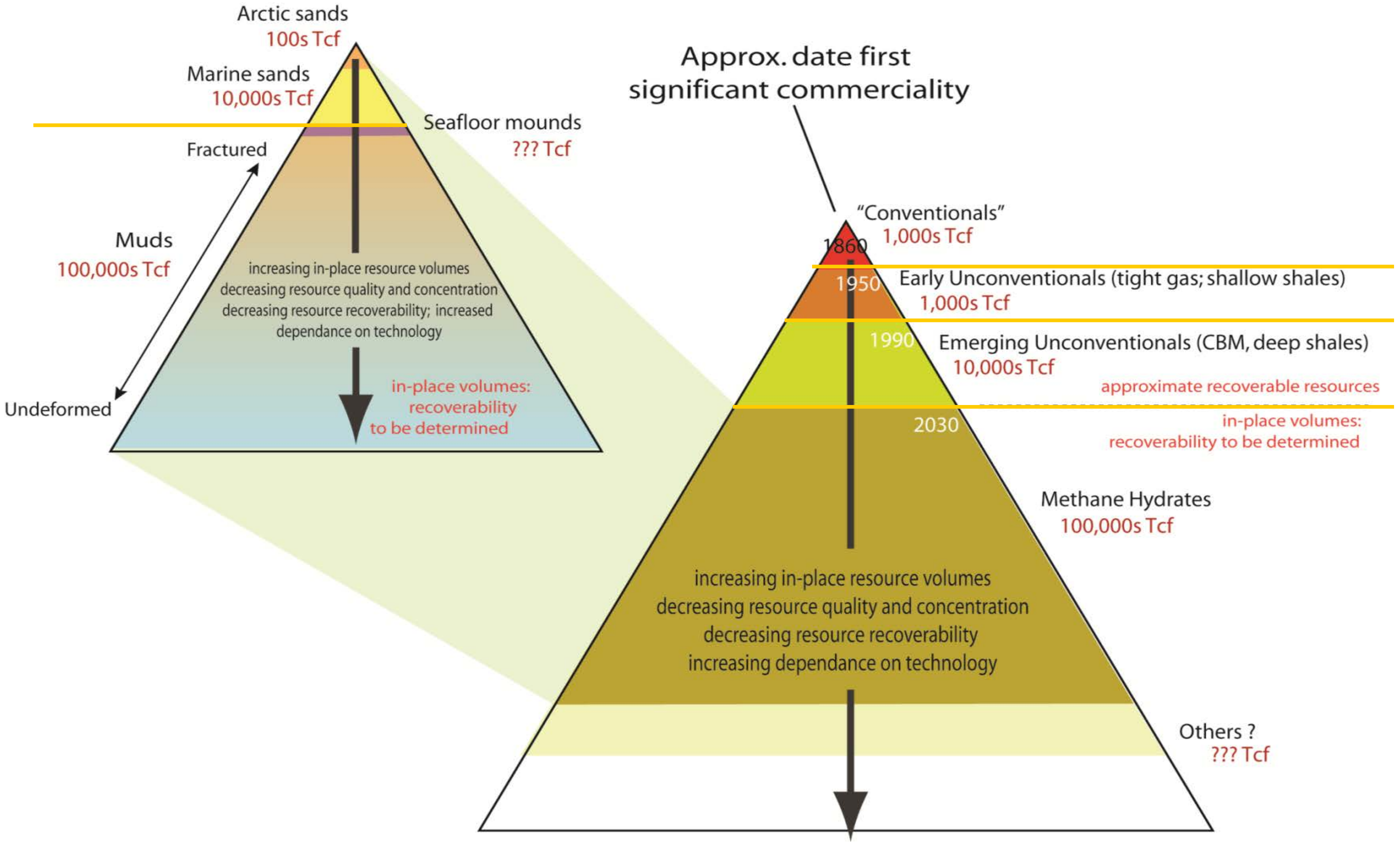


Presentation Outline

1. *Define what is a Gas Hydrate Resource vs. Reserve*
2. *Evolution of a Gas Resource to a Gas Reserve*
   - *Resource Characterization – where, how, why?*
   - *Production Technology*
   - *Motivations Leading to Gas Hydrate Production*
   - *Gas Hydrate Reserves – Commercial Production*
3. *Summary and Charge to the Convention*

Gas Resources

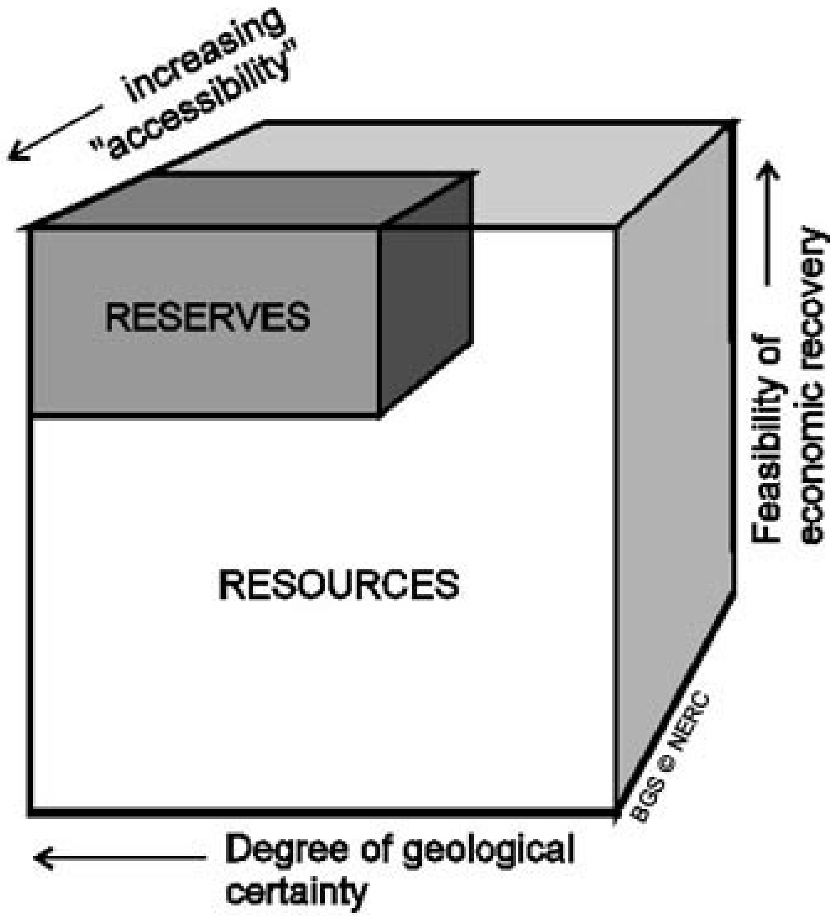
Conventionals and Unconventionals (including gas hydrates)



Modified from Boswell

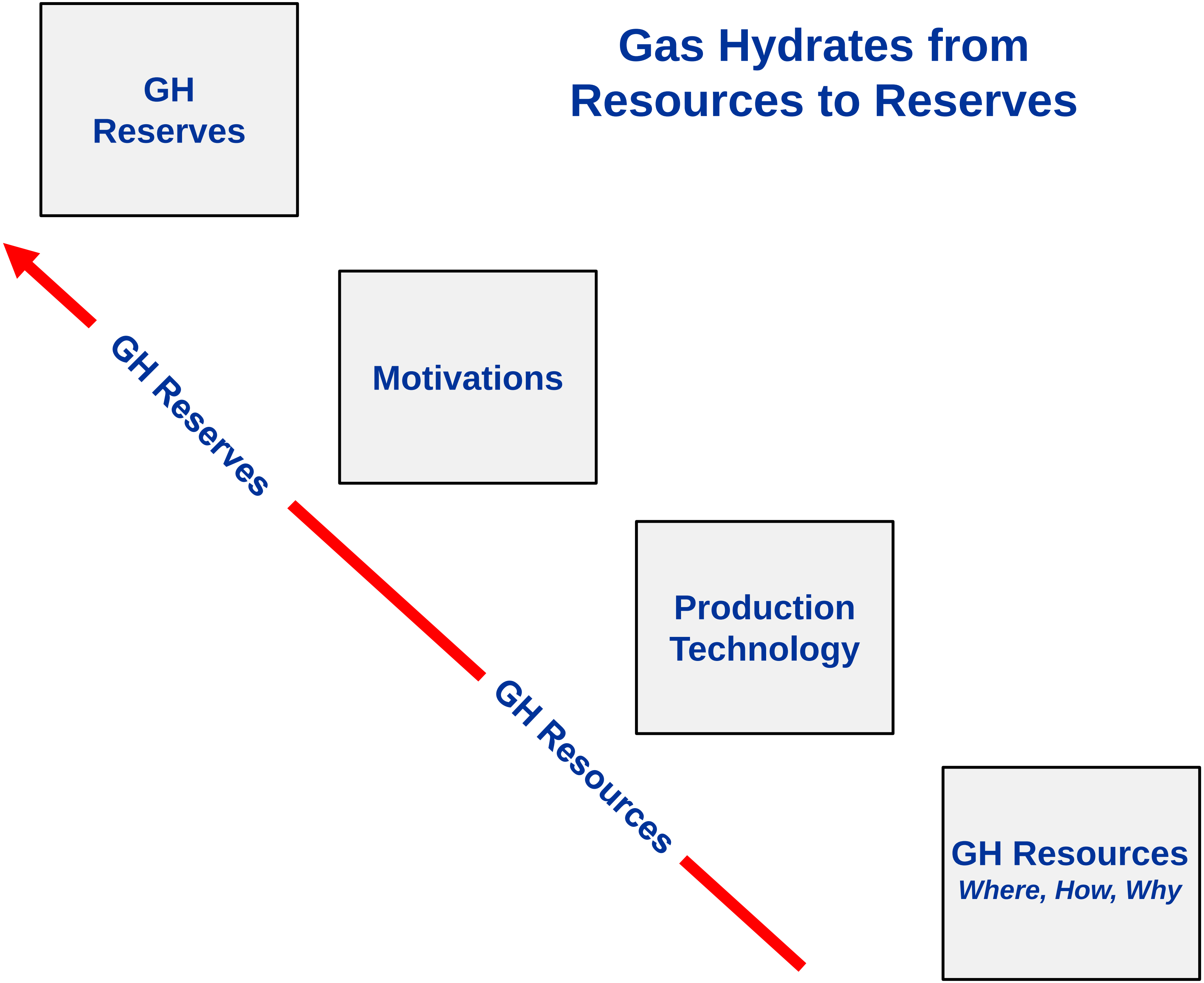
Gas Hydrate Resource Assessments

Resources vs. Reserves



*In this presentation the term **Resource** refers to the total amount of gas that exists, which is assumed to be the same as the **In Place** volume. This includes gas that is both discovered and undiscovered, economically recoverable or not economically recoverable.*

*Conversely, **Reserves** in this case are gas deposits that are known to exist with a reasonable level of certainty. These reserves are also recoverable economically with the technologies that already exist.*


Gas Hydrates from
Resources to Reserves
GH
Reserves
Motivations
Production
Technology
GH Resources
Where, How, Why
GH Reserves
GH Resources

Gas Hydrates from Resources to Reserves

GH Reserves

GH Resources

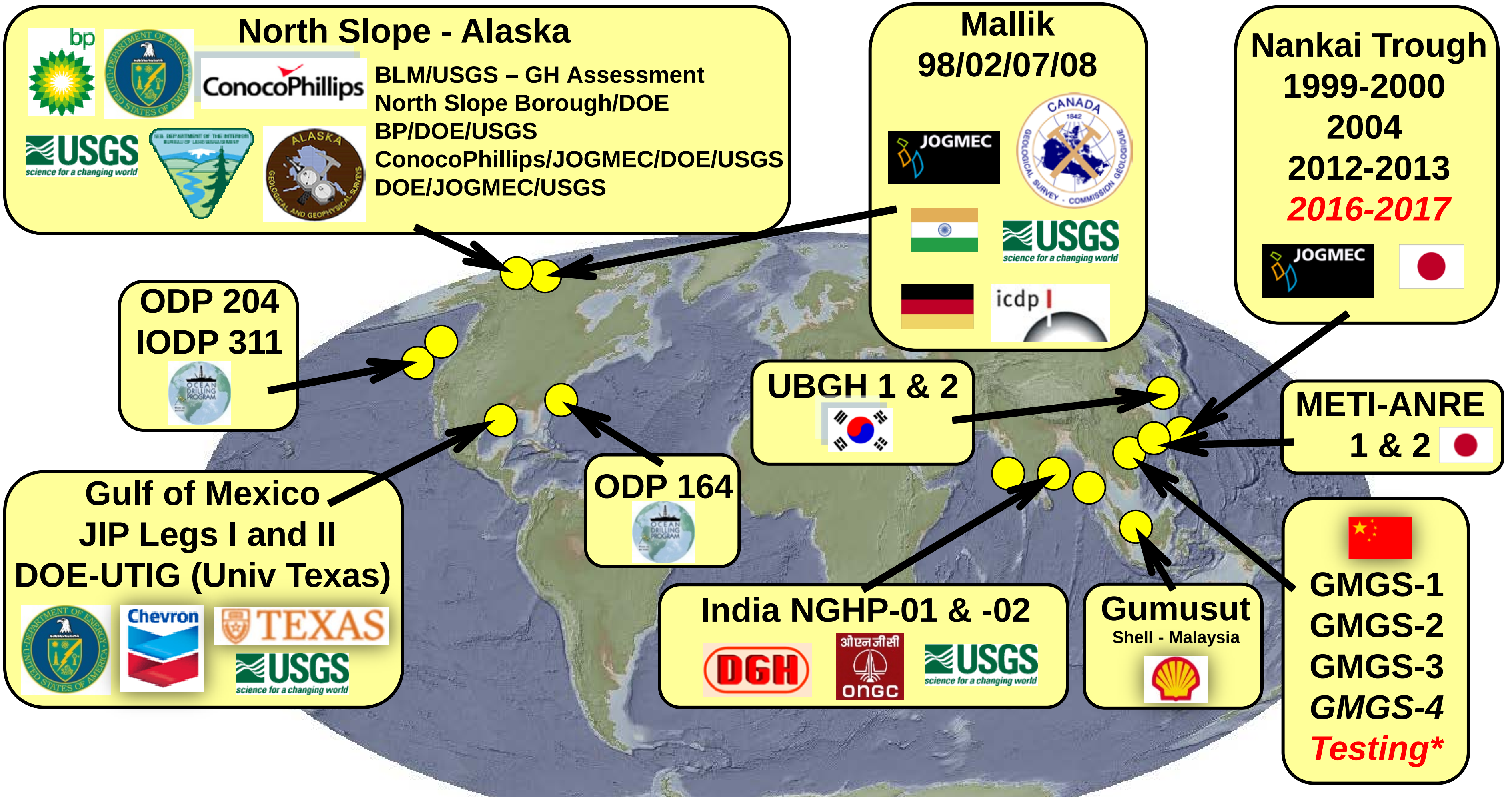
GH Reserves

Motivations

Production Technology

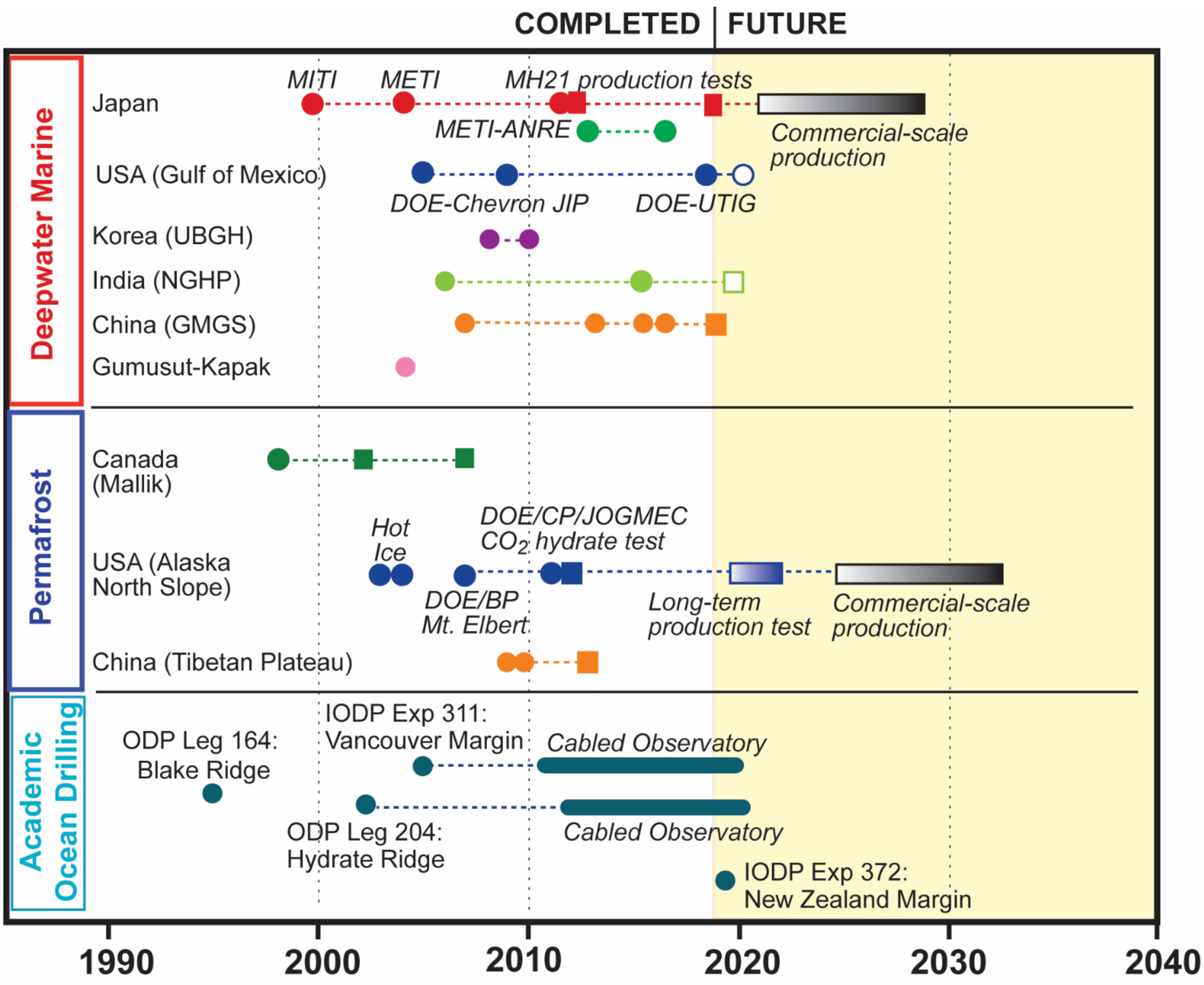
GH Resources
Where, How, Why

Gas Hydrate Scientific and Industry Drilling



*China Ministry of Land and Resources

Gas Hydrate Scientific and Industry Drilling



Gas Hydrates from Resources to Reserves

GH Reserves

Motivations

Production Technology

Geologist

GH Resources
Where, How, Why

GH Resources → GH Reserves

Gas Hydrates from Resources to Reserves

GH Reserves

GH Resources

GH Reserves

Motivations

Production Technology

GH Resources
Where, How, Why

Geologist
Geophysicist

GH Resources → GH Reserves

GH Reserves

- Japan (MITI/JOGMEC): Commercial production by 2023 to 2027
- India (MoP&NG): Commercial production by 2020
- SBC Energy Institute: Economic production of GH in the next 10-20 years
- Consensus: Industry experts say that commercial gas hydrate development could be possible after 2030. Smaller scale output could be possible as early as 2018 (associated with production testing)

Motivations

- Global Competition: Emergence of other gas and energy resources
- In most cases, unknown resource volume and unproven production technology
- Commercialization of GH at about twice the cost of conventional gas (maybe)
- Special National interest and local drivers
- Impact of taxation and climate change policies (royalties, carbon tax, etc)
- Industry interest and investment

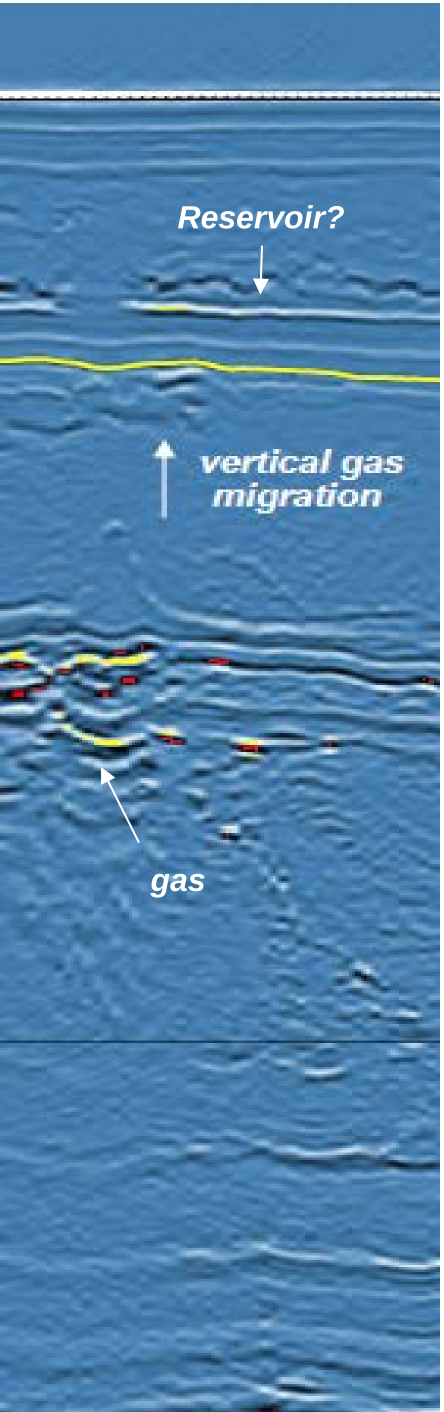
Production Technology

- Field testing and modeling have confirmed the viability of GH depressurization
- Important advances in petrophysical and mechanical properties analyses
- The further development and calibration of advance GH reservoir models
- Assessing the impact of GH production on reservoir and mechanical properties
- Investment in field testing and environmental studies (but limited)

GH Resources

Where, How, Why

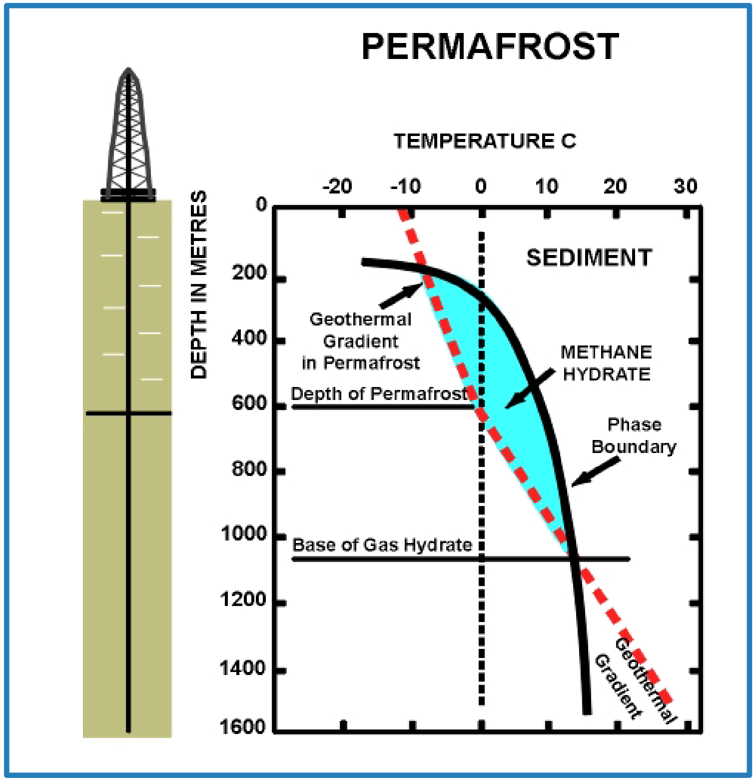
- **Development of the GH Petroleum System concept**
- **More than 25 major GH geoscience related projects/expeditions since 1995**
- **Advances in field data acquisition and analysis**
- **Advances in GH laboratory and modeling studies**
- **Geologic based GH assessments (in-place, technical recoverable, reserves est.*)***

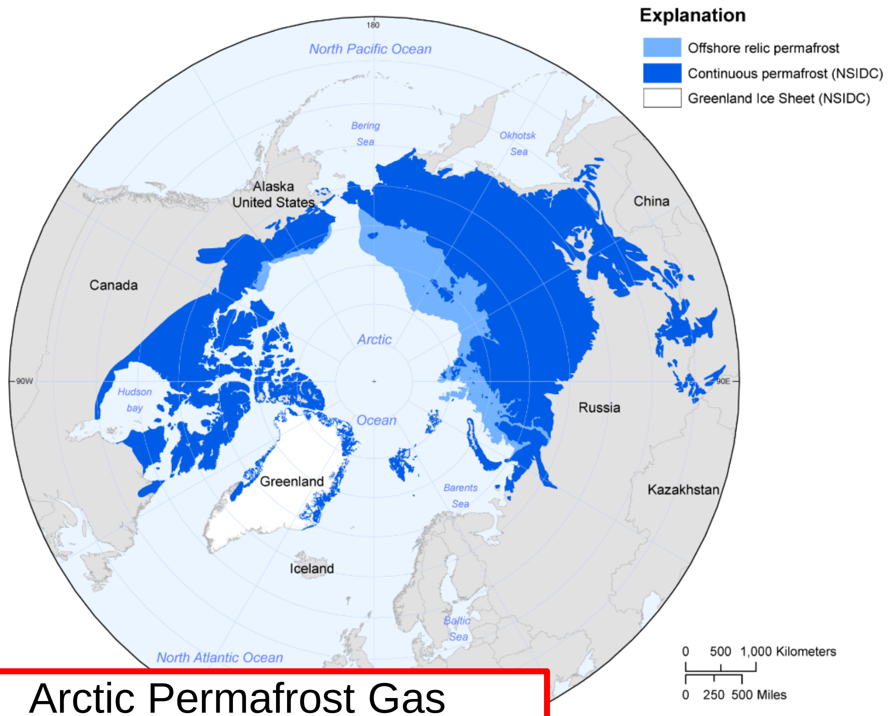


Gas Hydrate Petroleum System

- **Extent of GH Stability Zone**
  - Formation temperature
  - Formation pressure
  - Pore water salinity
  - Gas chemistry
- **Gas Source and Migration - Charge**
  - Availability of gas and water (source)
  - Gas and water migration pathways
- **Reservoir**
  - Presence of reservoir rocks
  - Trap and seals

Gas Hydrate Stability Conditions

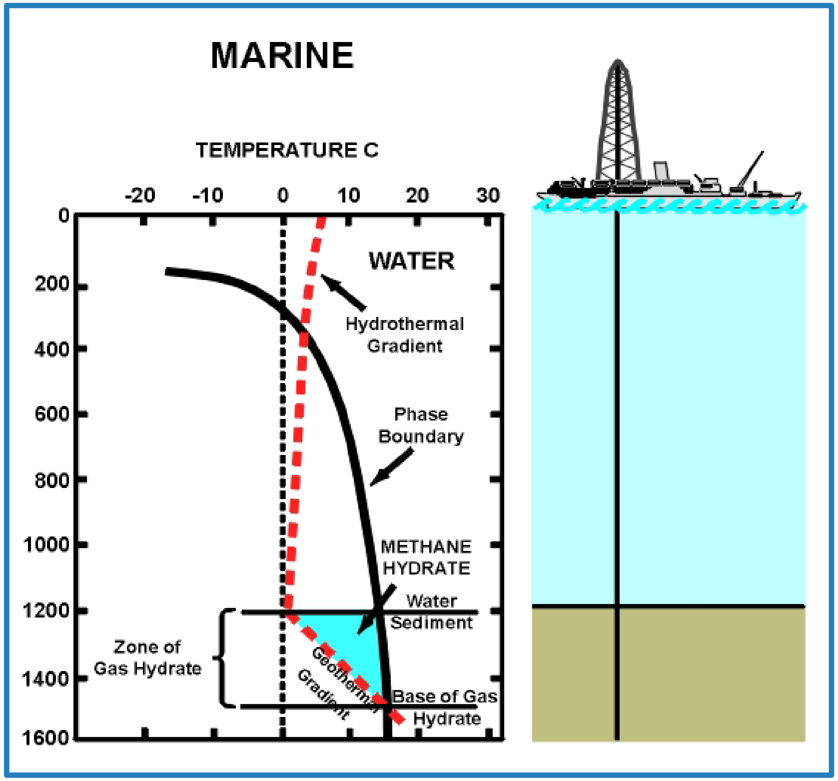


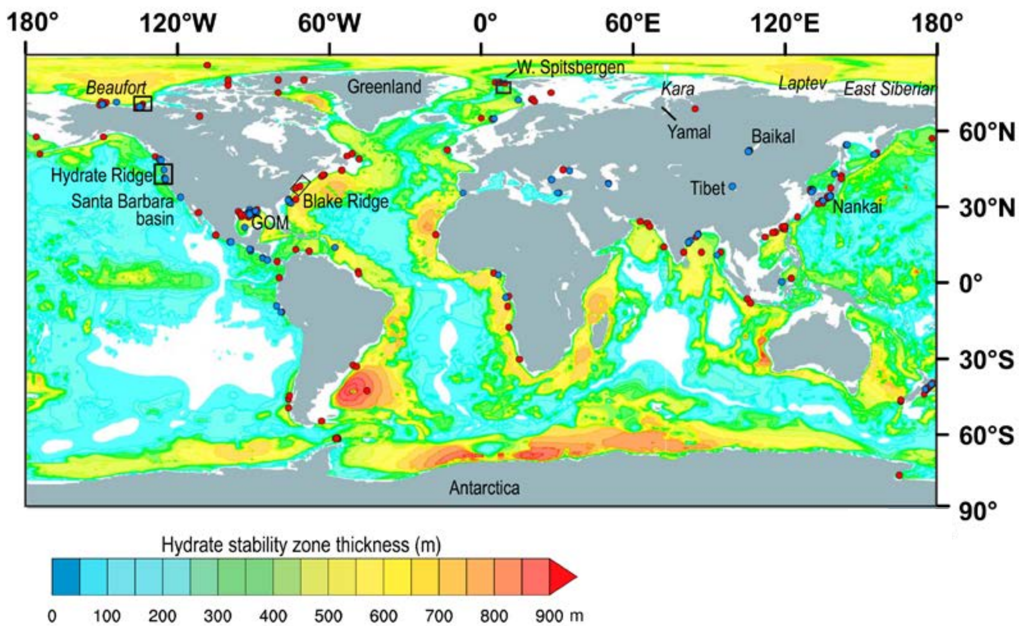


Arctic Permafrost Gas Hydrate Stability Conditions

Max and Lowrie, 1992
Collett et al., 2009

Gas Hydrate Stability Conditions

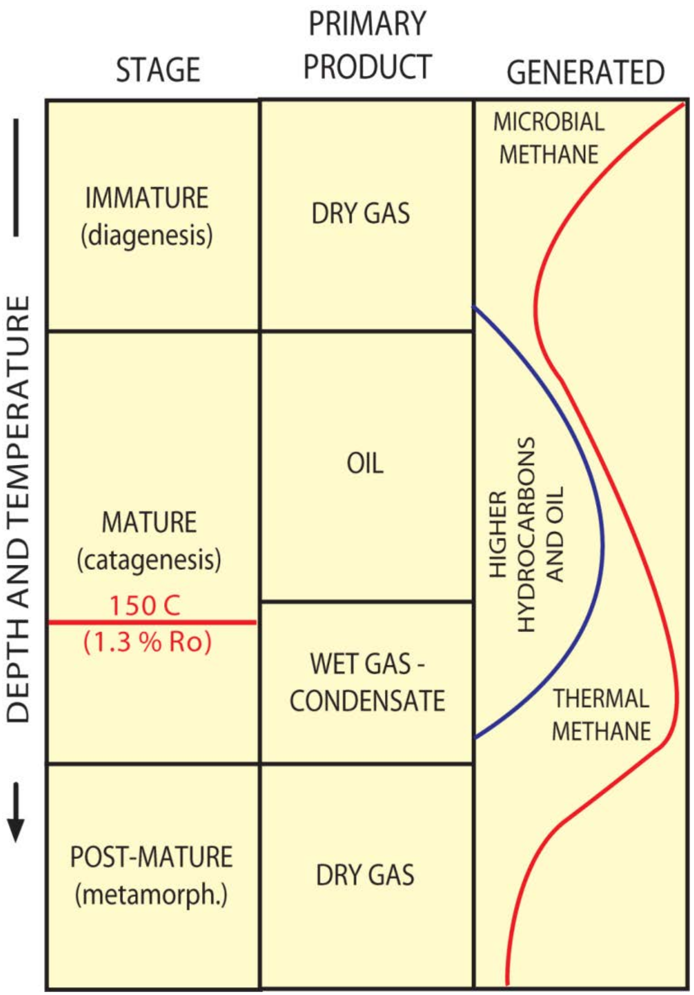




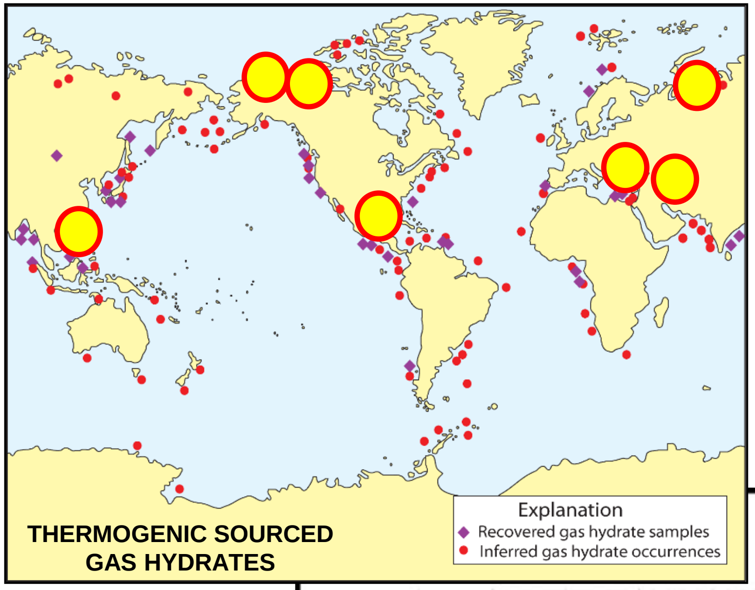
Ruppel and Kessler, 2017

Gas Hydrate Petroleum System

Gas Source and Migration



Microbial vs. Thermogenic Gas Systems

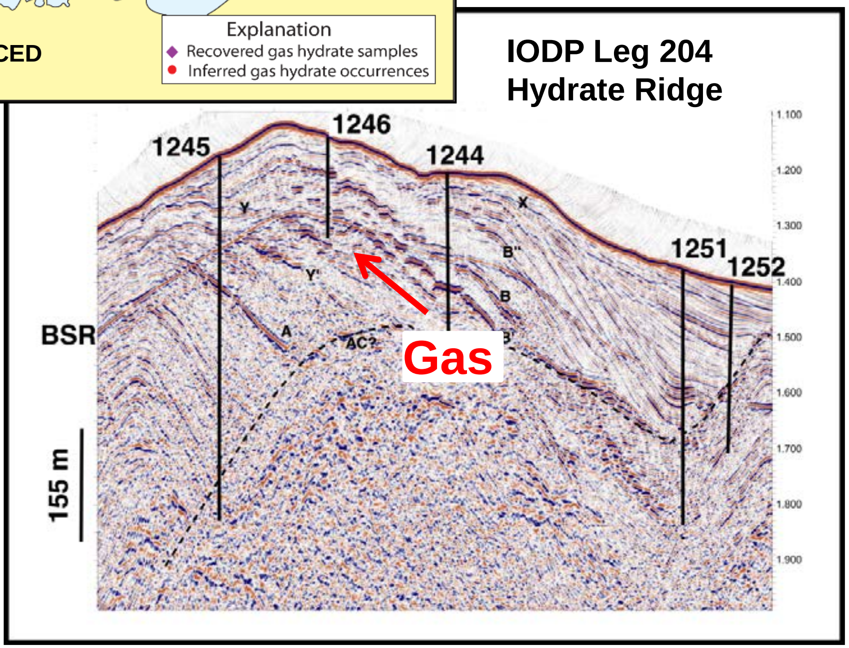


Gas Migration

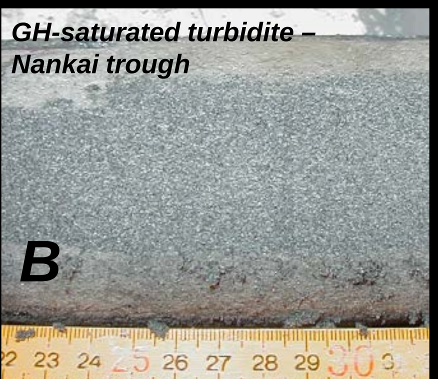
1. Diffusion

2. Dissolved gas

3. Separate phase

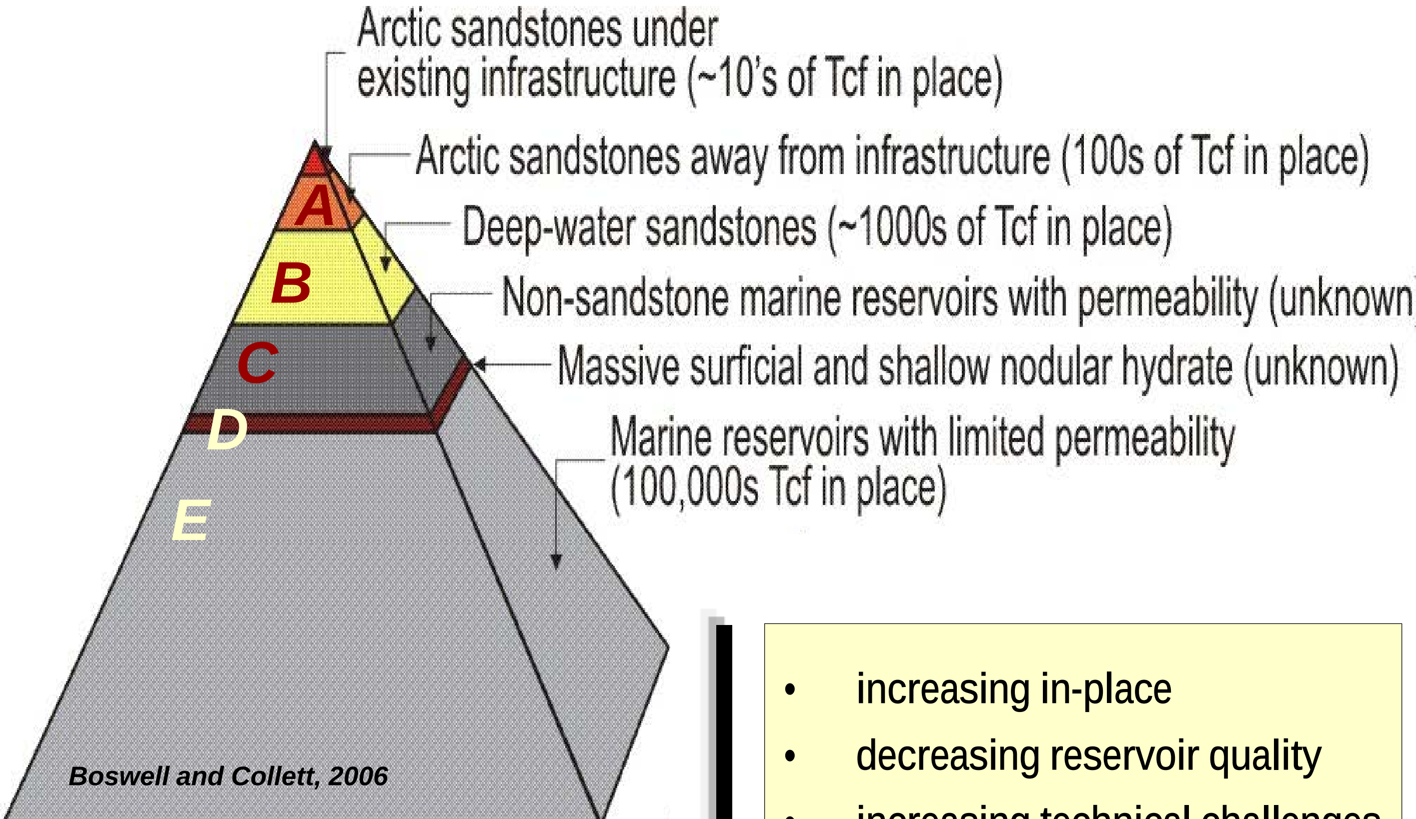


Tréhu et al., 2004



The Gas Hydrates Resource Pyramid

Distribution of huge in-place resource



Data Sources
A: USGS, 2008 (USGS, 1995)
B: MMS, 2008
C: Unassessed (India, Korea expeditions)
D: Unassessed
E: USGS, 1995

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

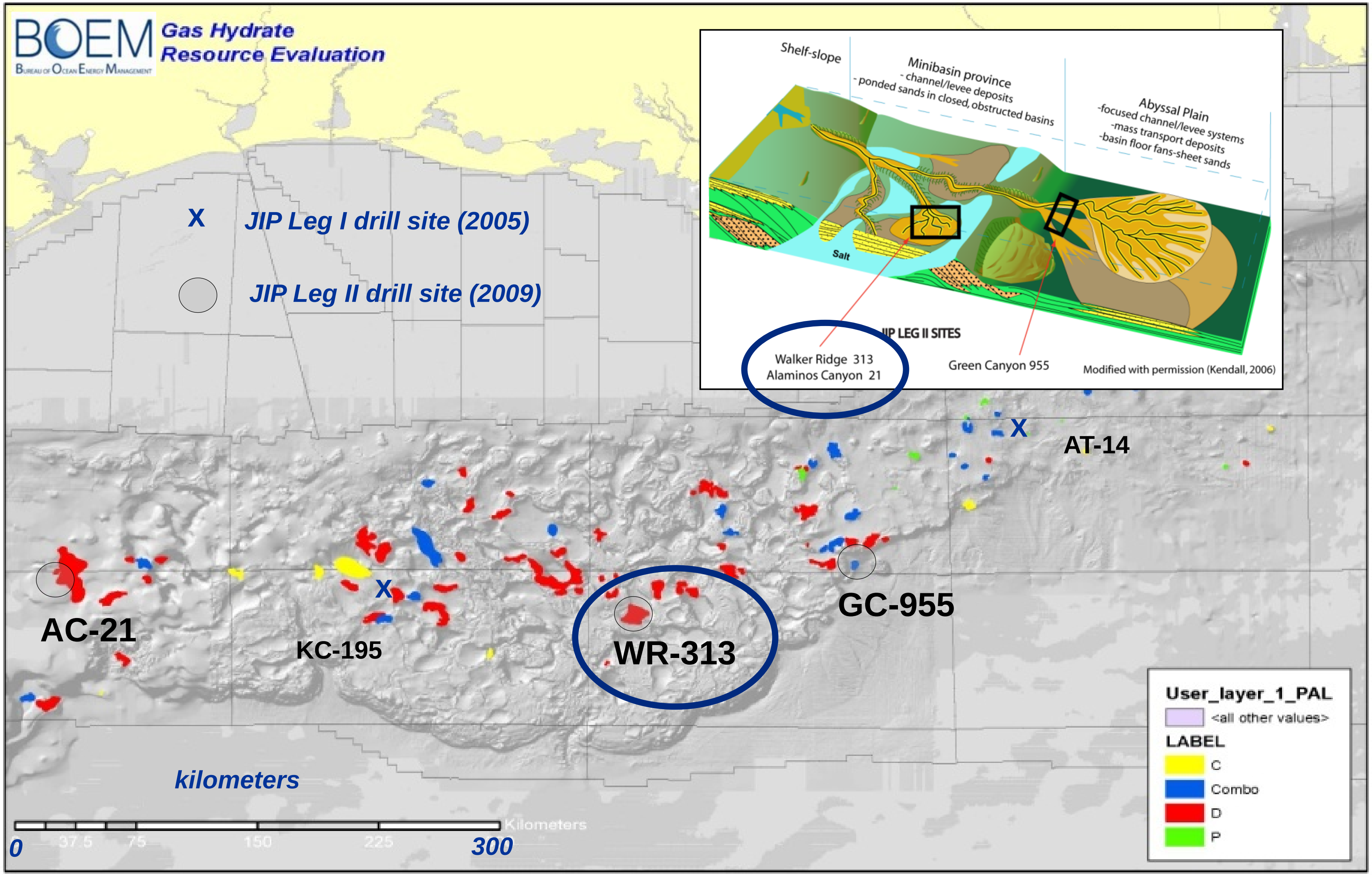
- **Gulf of Mexico, USA**

  JIP Legs I and II, UT-GOM2-1

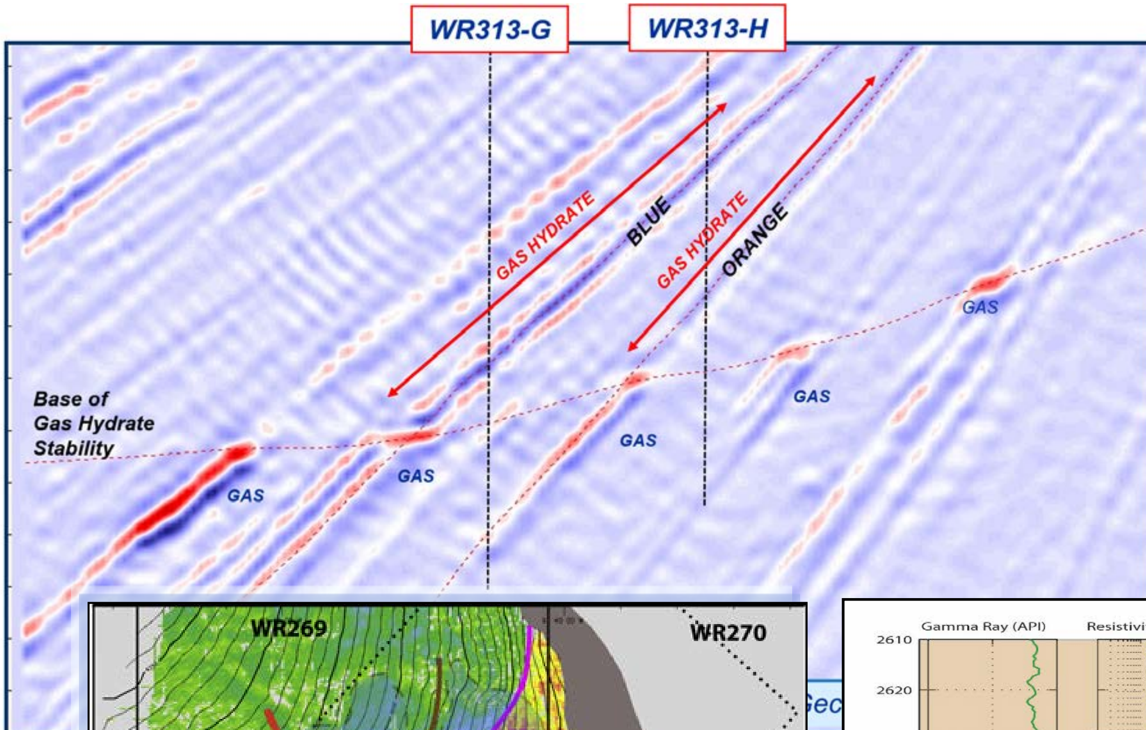
JIP Leg II Expedition 2009 Drill Sites

With BOEM Map of Seismic Inferred Gas Hydrates

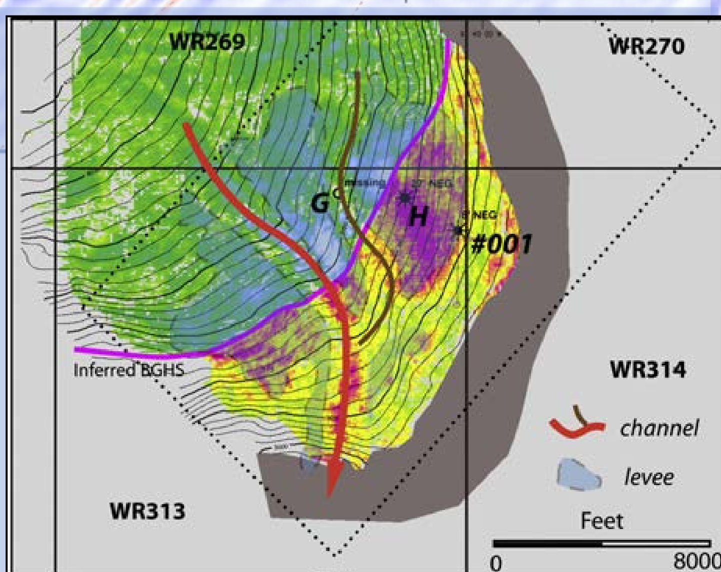
C = continuous; Combo = combination; D = discontinuous; P = patchy

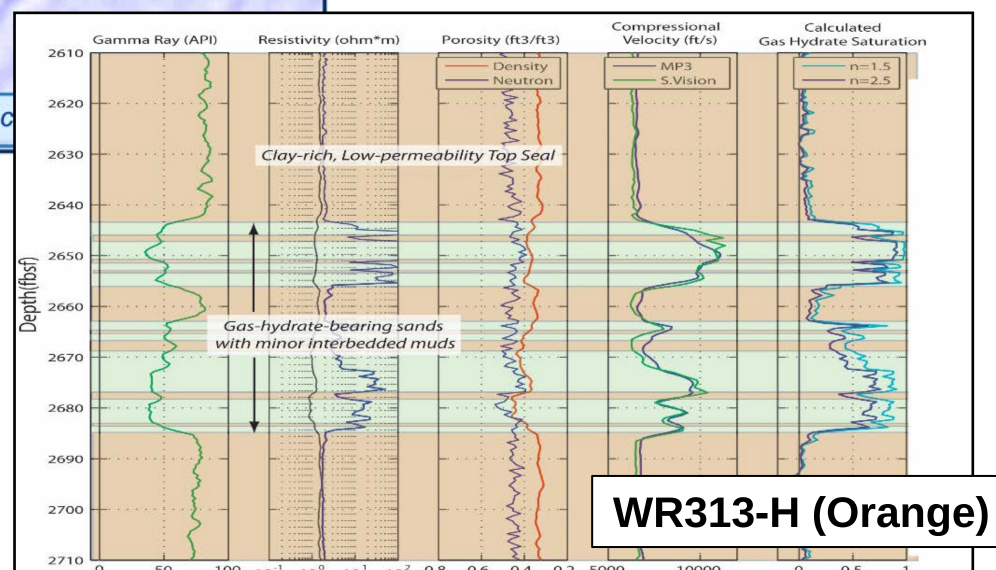


JIP Leg II Expedition 2009 – Site WR313



- Prospecting effort identified multiple potential sites
- Two LWD wells drilled
- GH concentrations matched predictions
- Confirmed Exploration Approach
- Established world-class gas hydrate research sites

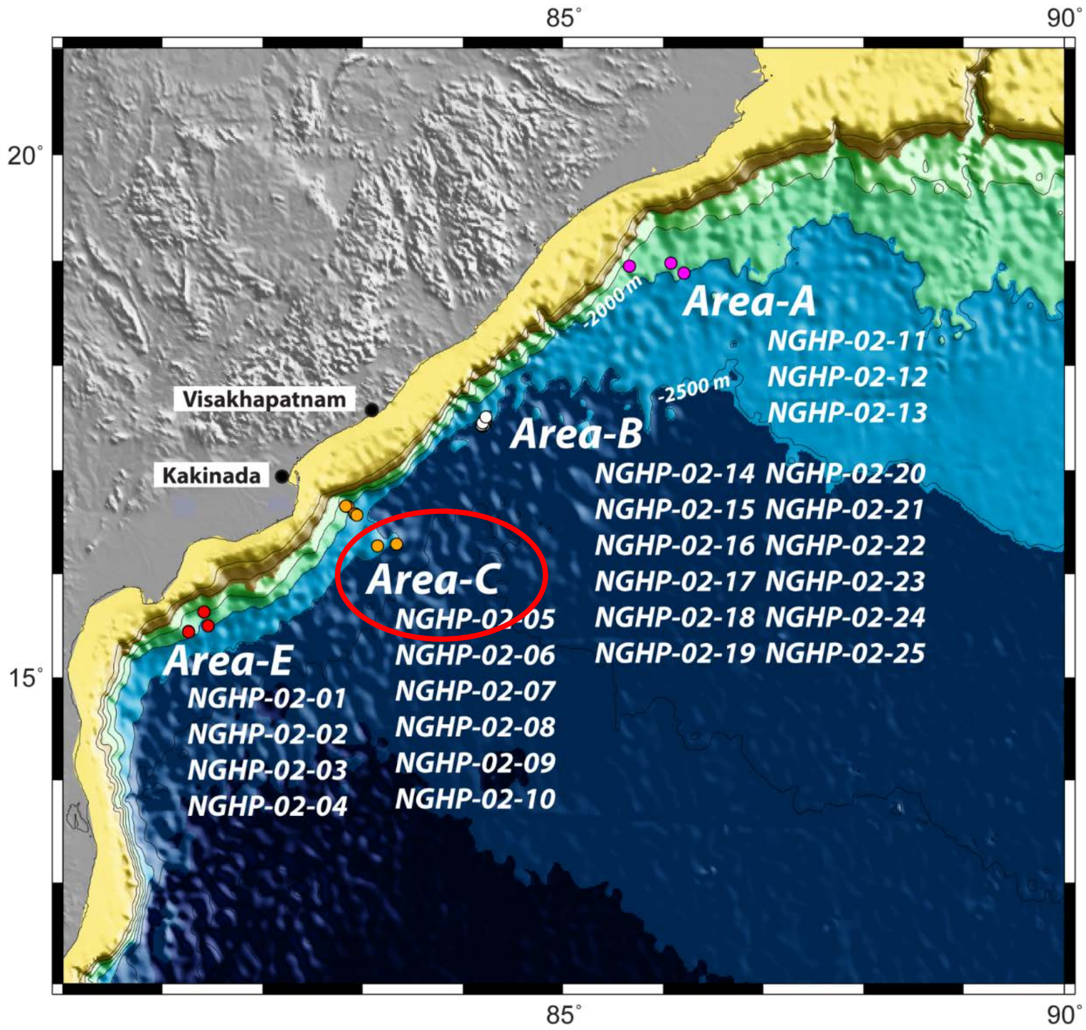




- ***Krishna-Godavari Basin, India***

NGHP-01 & NGHP-02, NGHP-03 Planning

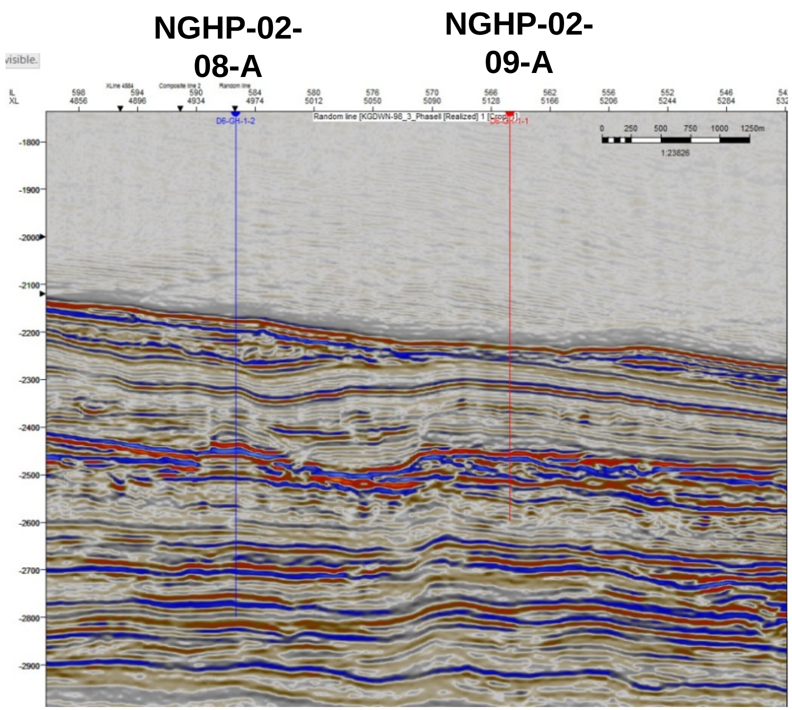
India NGHP-02 (2015)

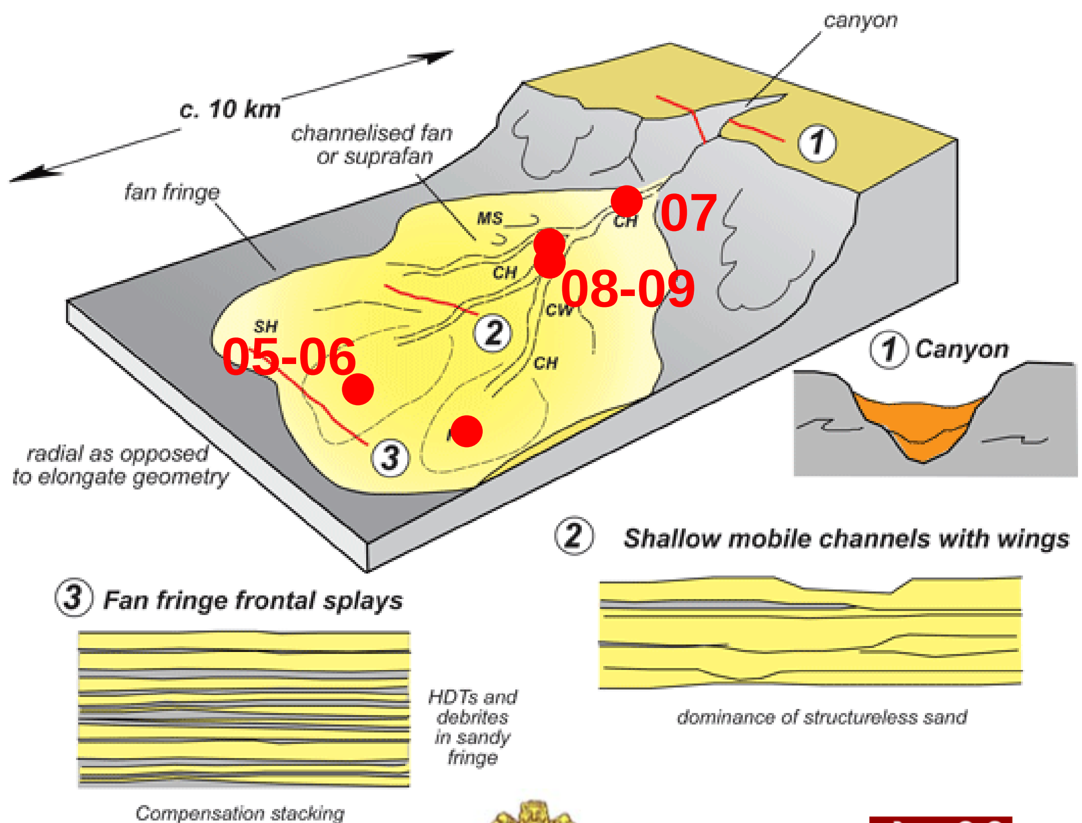


- Advance pre-drill prospect review
- Total of 42 holes were completed in 147 days. Water depths 1,519-2,815 m
- Total of 25 LWD holes, conventional and pressure (106) cores were acquired in 16 wells, wireline logging and MDT testing
- Concentrated GH reservoir systems in both Area-B and Area-C matching pre-drill site review predictions
- Area-B and Area-C contain important gas hydrate accumulations and represent ideal sites for future gas hydrate production testing

सत्यमेव जयते

India NGHP-02 (2015): Area-C





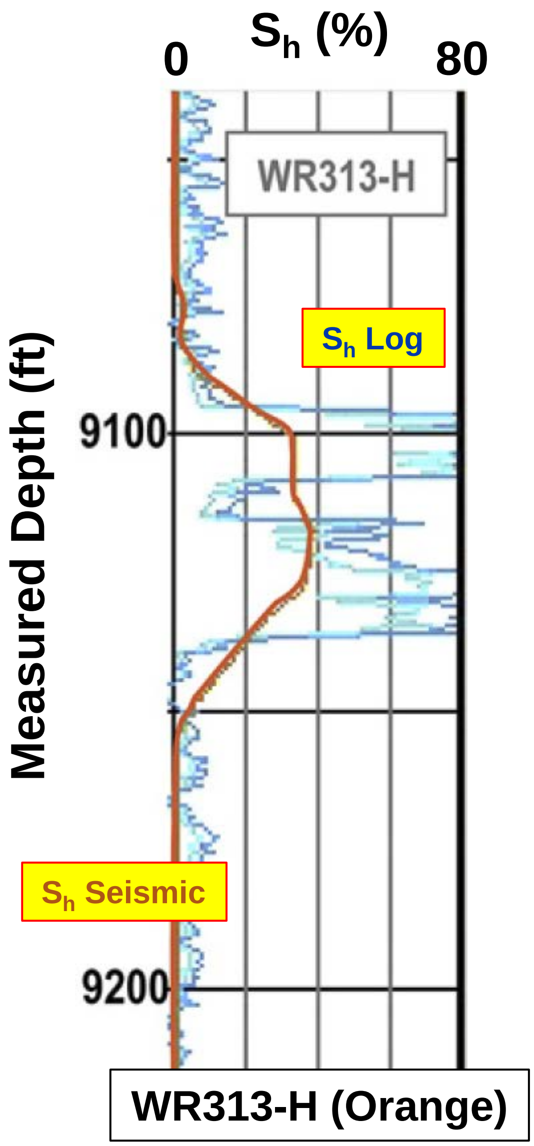

Core NGHP-02-09B-35P

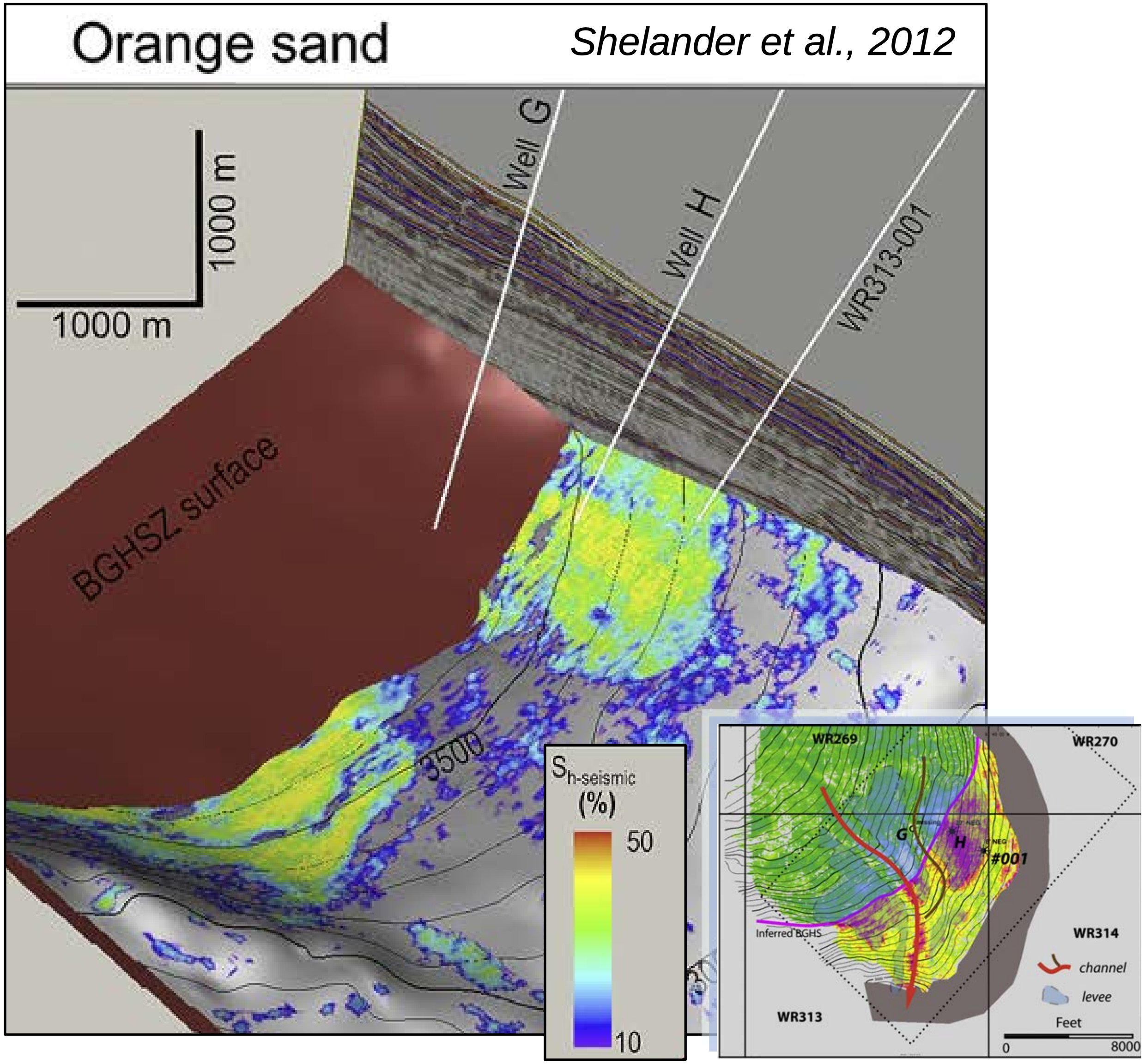
Area C: Krishna-Godavari Gas Hydrate Petroleum System

Slope-Rise Channel-Levee System

JIP Leg II Expedition 2009 – Site WR313

Seismic Inversion





Gas Hydrate Well Log Analysis

Well log	Application
Density	Porosity
Neutron Porosity	Porosity
Electrical Resistivity	GH Saturation Texture
Acoustic Velocity	GH Saturation Texture
Neutron Spectroscopy	GH Saturation
NMR	GH Saturation Porosity Permeability

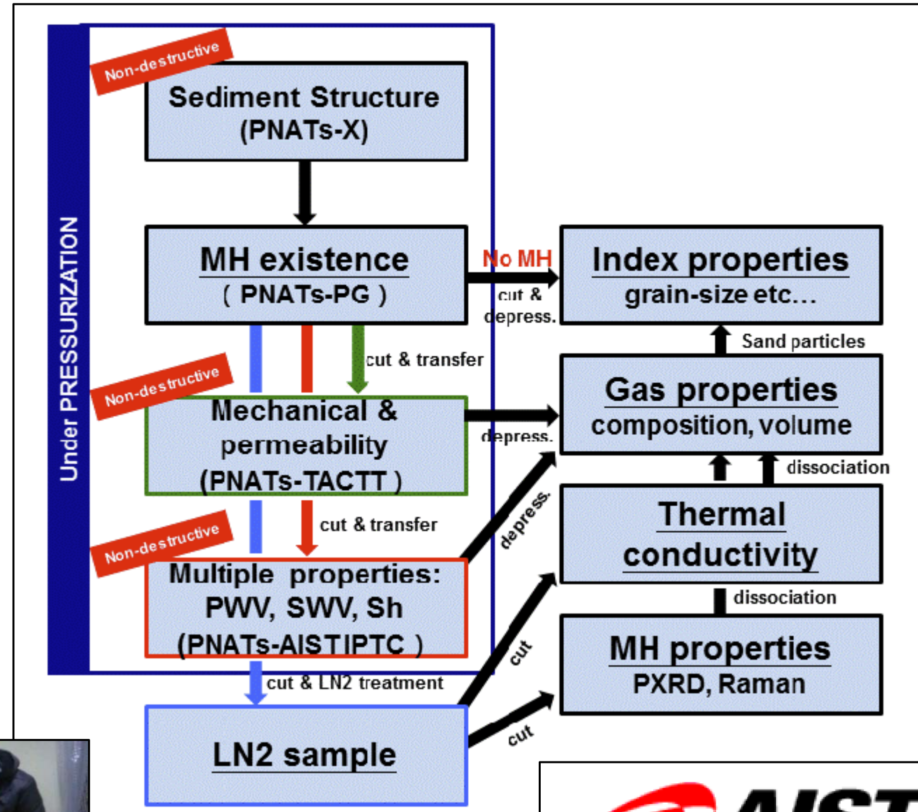
GOM JIP Leg II featured a state-of-the-art LWD bottom hole assembly

- *23.2' x 8.375" SonicVision*
- *18.3' x 7.5" PeriScope*
- *32' x 8.25" TeleScope*
- *25.2' x 8.25" EcoScope*
- *10' x 8.25" GeoVision*
- *6.75" x 8.50" Hole opener*
- *31' x 6.5" SonicScope (MP3)*
- *6.75" PDC bit*

LWD tools by Schlumberger

Gas Hydrate Pressure Coring

Pressure Core Analysis: Geotek-PCATS, AIST, USGS/GT, UT



AIST
NATIONAL INSTITUTE OF ADVANCED INDUSTRIAL SCIENCE AND TECHNOLOGY (AIST)

PCCTS

USGS science for a changing world

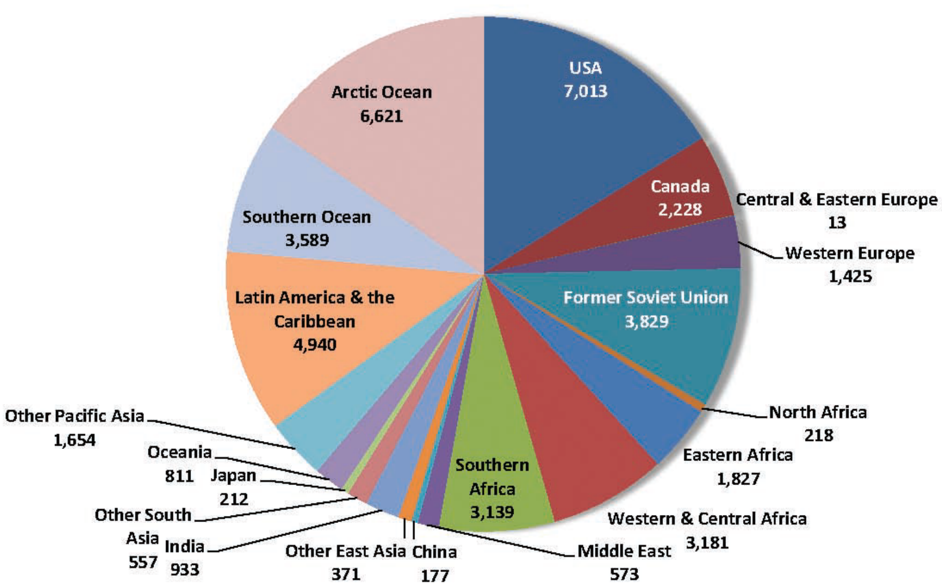
Georgia Tech

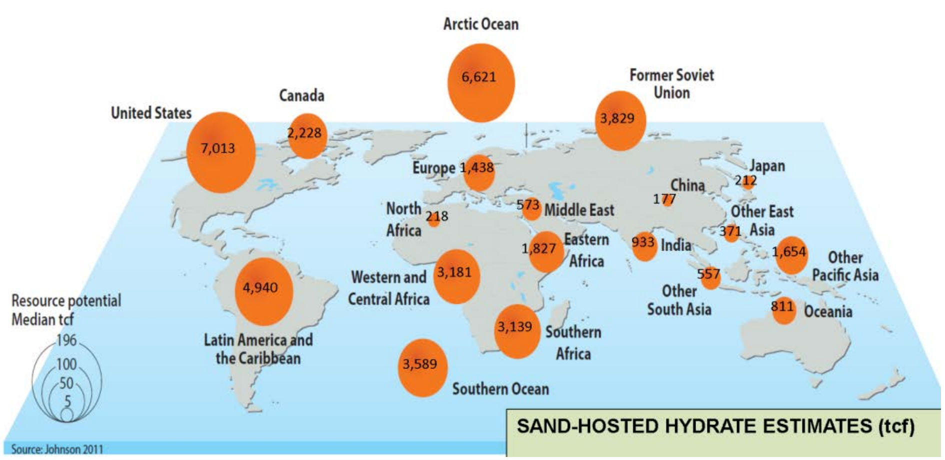
Global Resource Potential of Gas Hydrate

Arthur Johnson, Hydrate Energy International

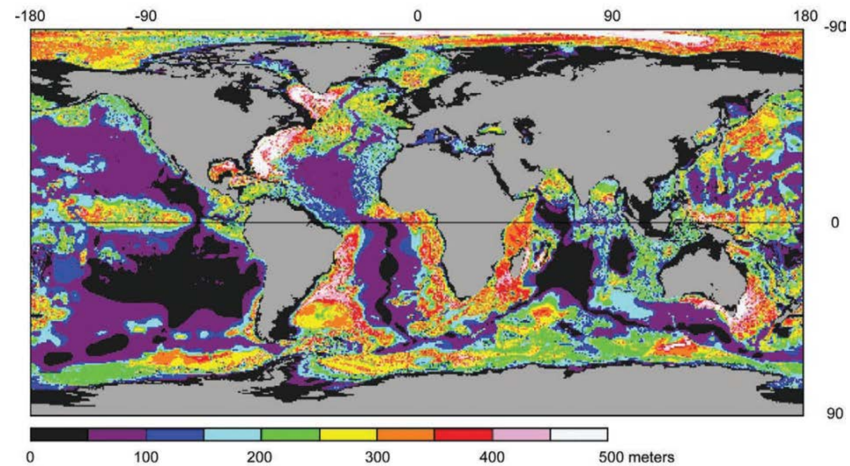
Calculated Gas In-Place in Hydrate-Bearing Sands

Total Median = 43,311 tcf





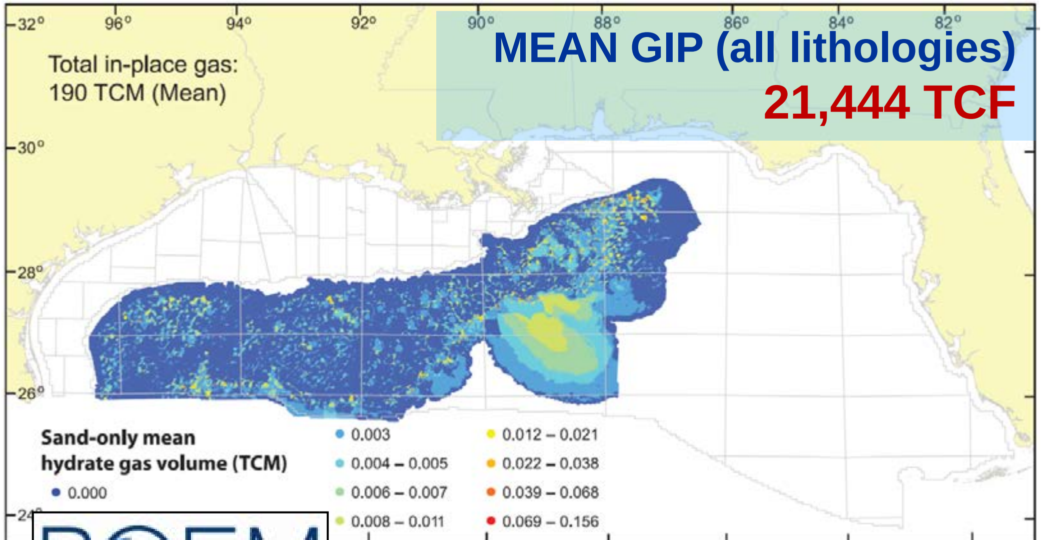
Methane Hydrate Stability Zone Thickness

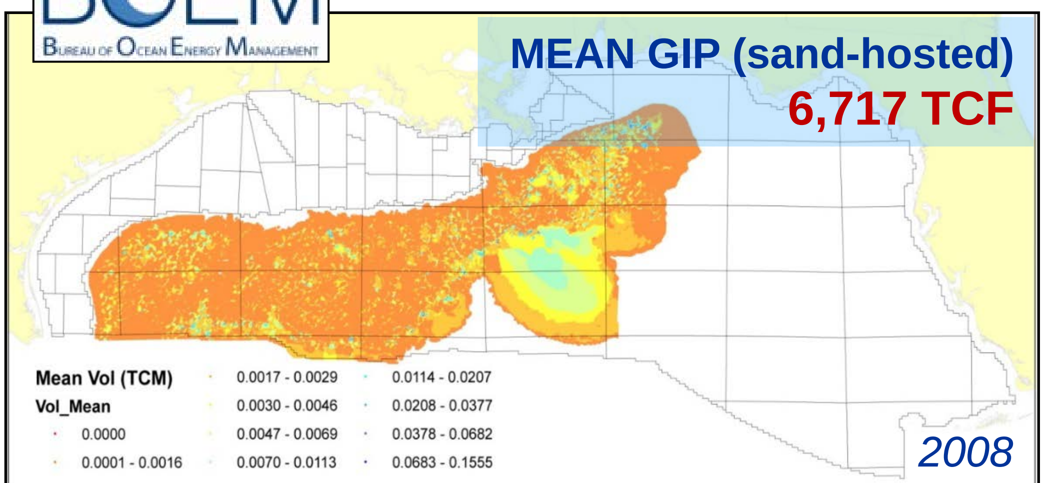


Methodology:

- Percentage of sand within the GHSZ
- Percentage reservoirs with hydrate
- Sand reservoir porosities
- Gas hydrate saturation

US-BOEM Gulf of Mexico GH Assessment





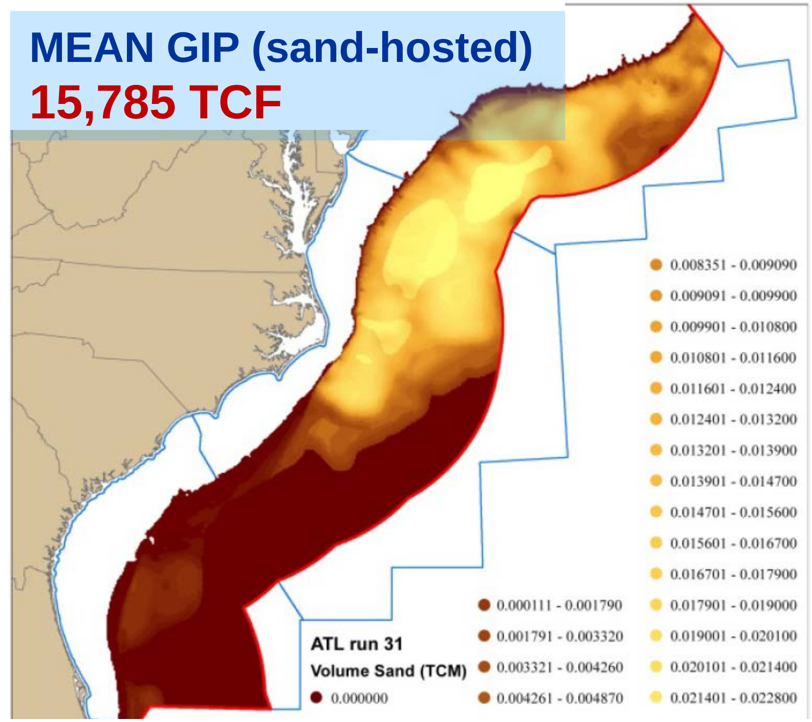


Table 1. BOEM in-place gas hydrate resource volumes for the Atlantic, Pacific, and Gulf of Mexico Outer Continental Shelf. Units are trillion cubic feet; 1 x 10^{12} ft^3. Resource volumes have not been subject to geologic risk.

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

Gas Hydrates from Resources to Reserves

GH Reserves

GH Resources

GH Reserves

Motivations

Production Technology

GH Resources
Where, How, Why

Current Challenges

Refined GH resource assessments, evolving from in-place (resource) to technical recoverable and reserve estimates

Integrated GH modeling, laboratory, and field system R&D

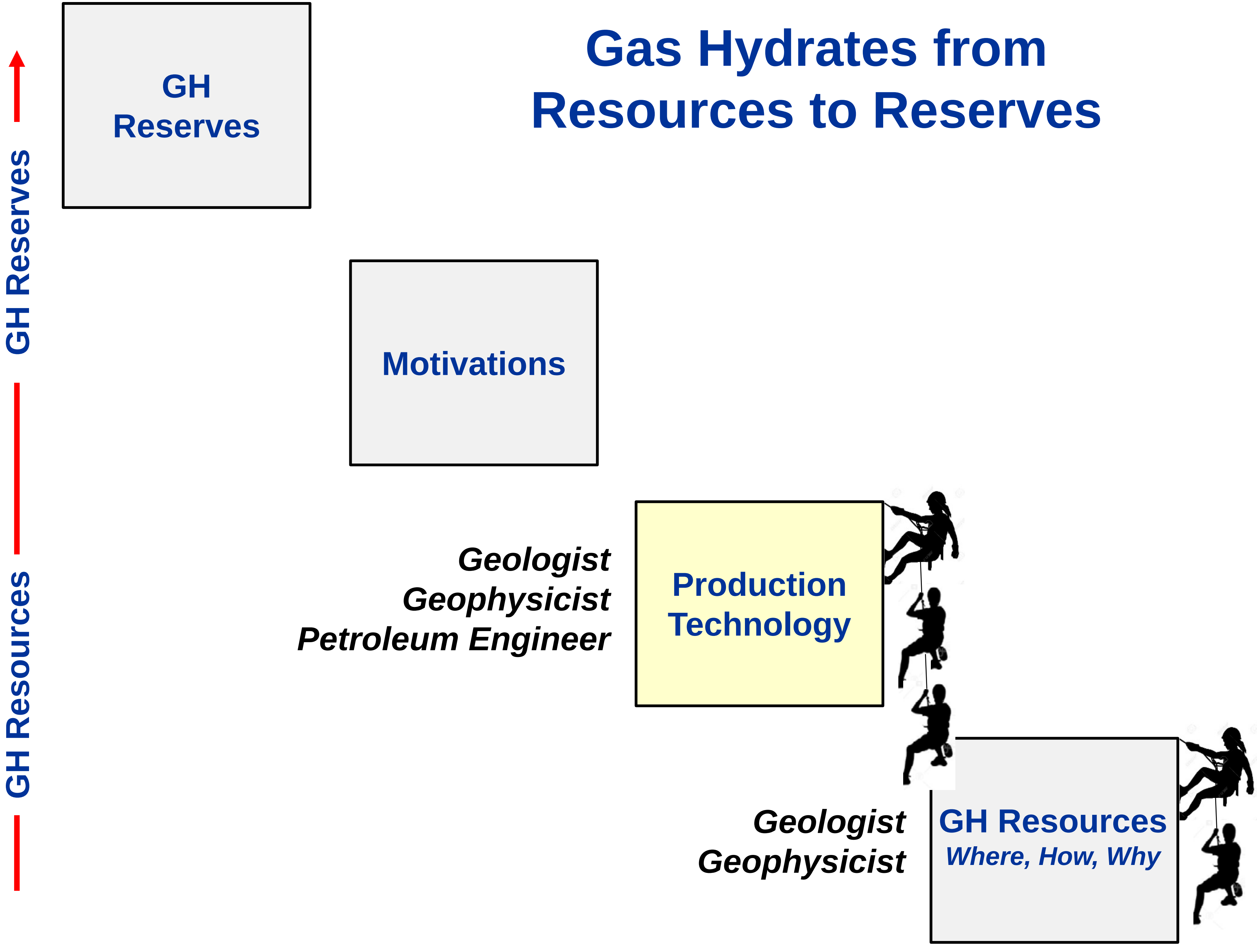
Advance integration and upscaling of model, lab, and field derived data

Develop and perform laboratory measurements to calibrate and interpret field data

Develop and deploy new and improved field characterization tools to address the critical GH science/engineering requirements

Further develop and refine GH prospecting techniques

Gas Hydrates from Resources to Reserves



GH Reserves

GH Resources

GH Reserves

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- **Important advances in petrophysical and mechanical properties analyses**
- **The further development and calibration of advance GH reservoir models**
- **Assessing the impact of GH production on reservoir and mechanical properties**
- **Investment in field testing and environmental studies (but limited)**

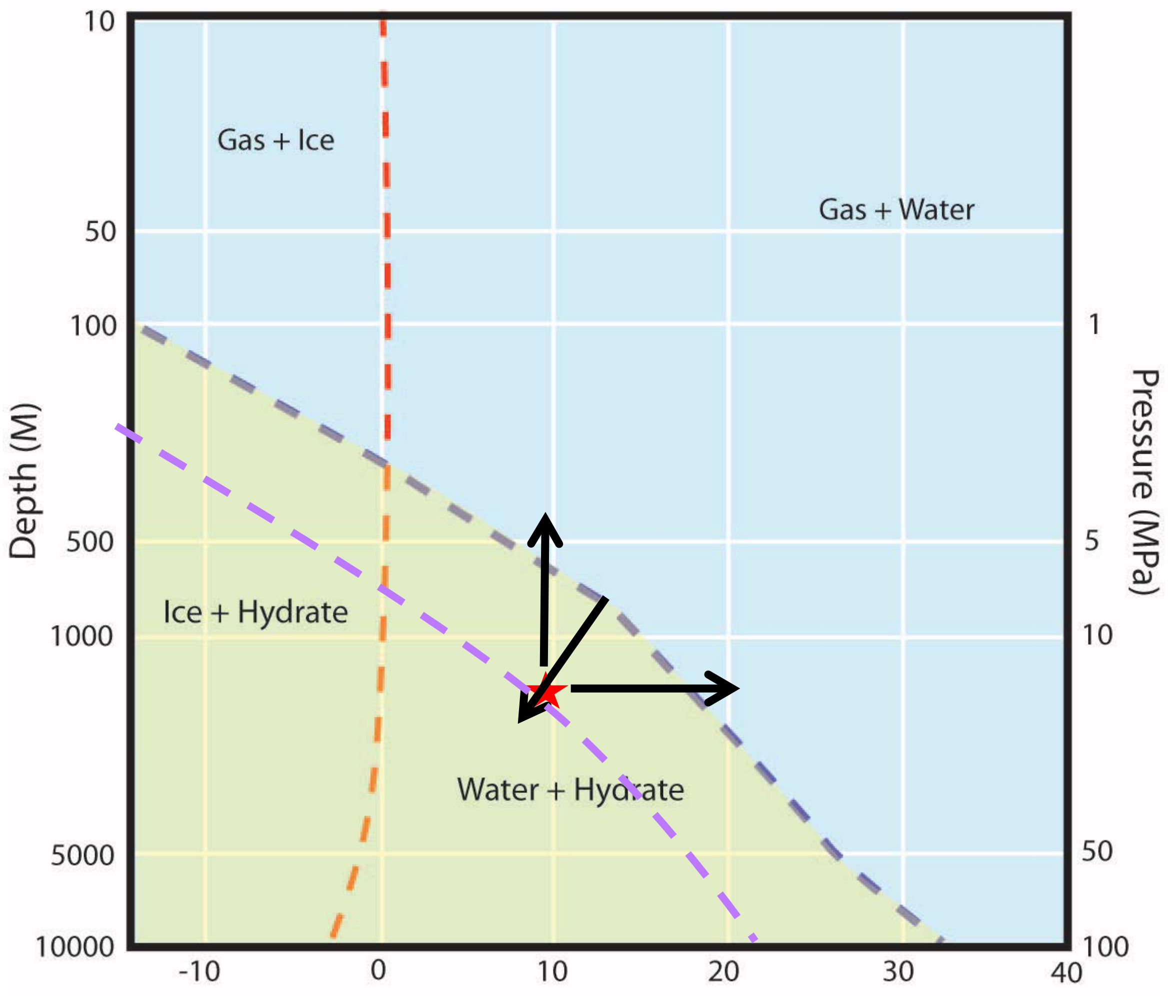
GH Resources

Where, How, Why

- Development of the GH Petroleum System concept
- More than 25 major GH geoscience related projects/expeditions since 1995
- Advances in field data acquisition and analysis
- Advances in GH laboratory and modeling studies
- Geologic based GH assessments (in-place, technical recoverable, reserves est.*)*

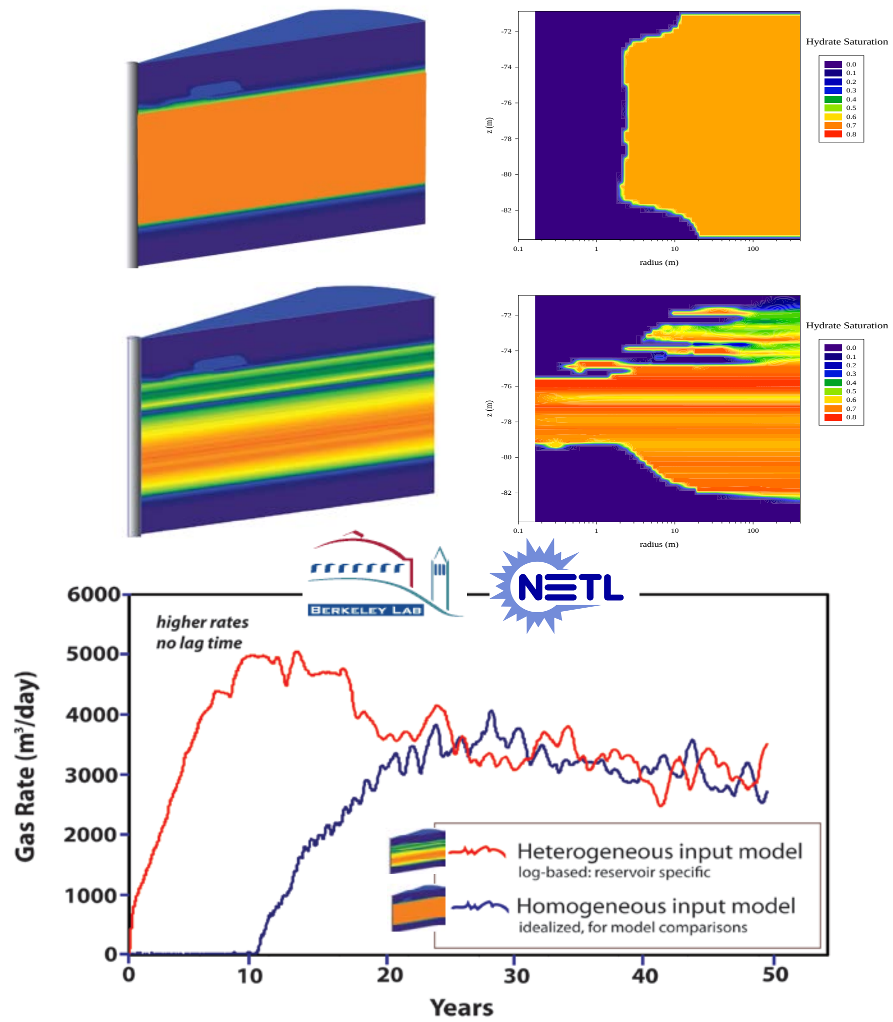
Gas Hydrate Production Concepts

- **Depressurization**
- **Heating**
- **Inhibitor Injection**
- **Chemical Exchange**
  - CO_2 sequestration

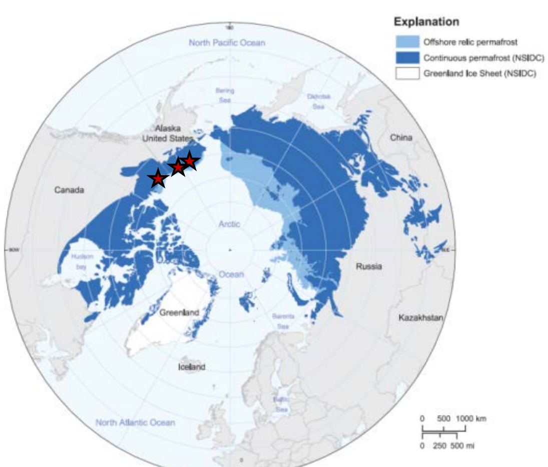


Gas Hydrate Production Modeling

- **Early 2000s**
  - Low rates, long lag times, large cumulatives but very long production profiles
- **Today**
  - High sensitivity to reservoir quality, heterogeneity, temperature
  - Intriguing rates obtainable in certain settings: 1s to 10s MMcf/d with minimal lag times, short production profiles
  - Recoverability theoretically high (60-80%)



Gas Hydrate Production R&D



- **Messoyakha (Russia) in the 1970s**
  - Hydrate supported gas production (?)
- **Industry Drill-Stem Tests in the 1970s**
  - NW Eileen St 2; Mallik 1L-38
- **1998, 2002 Mallik (Canada)**
  - Thermal and formation pressure testing
- **2007 BP-DOE-USGS Alaska**
  - Formation pressure testing
- **2007 & 2008 Mallik (Canada)**
  - Depressurization test (6-days)
- **2011-2102 ConocoPhillips-DOE Alaska**
  - CH_4-CO_2 exchange and depressure test (25-days)
- **2013 Nankai Trough Offshore Test (Japan)**
  - 1st Marine GH production test (6-days)
- **2017 South China Sea Test (China)**
  - Marine GH production test (7.8-days*)*
- ***2017 Nankai Trough Test (Japan)***
  - *Marine GH production test (Started May 4, 2017)*
- ***2017-2019 DOE-JOGMEC Alaska***
  - *Extended depressurization testing*
- ***2018-2019 KG Basin Offshore Test (India)***
  - *Extended depressurization test*

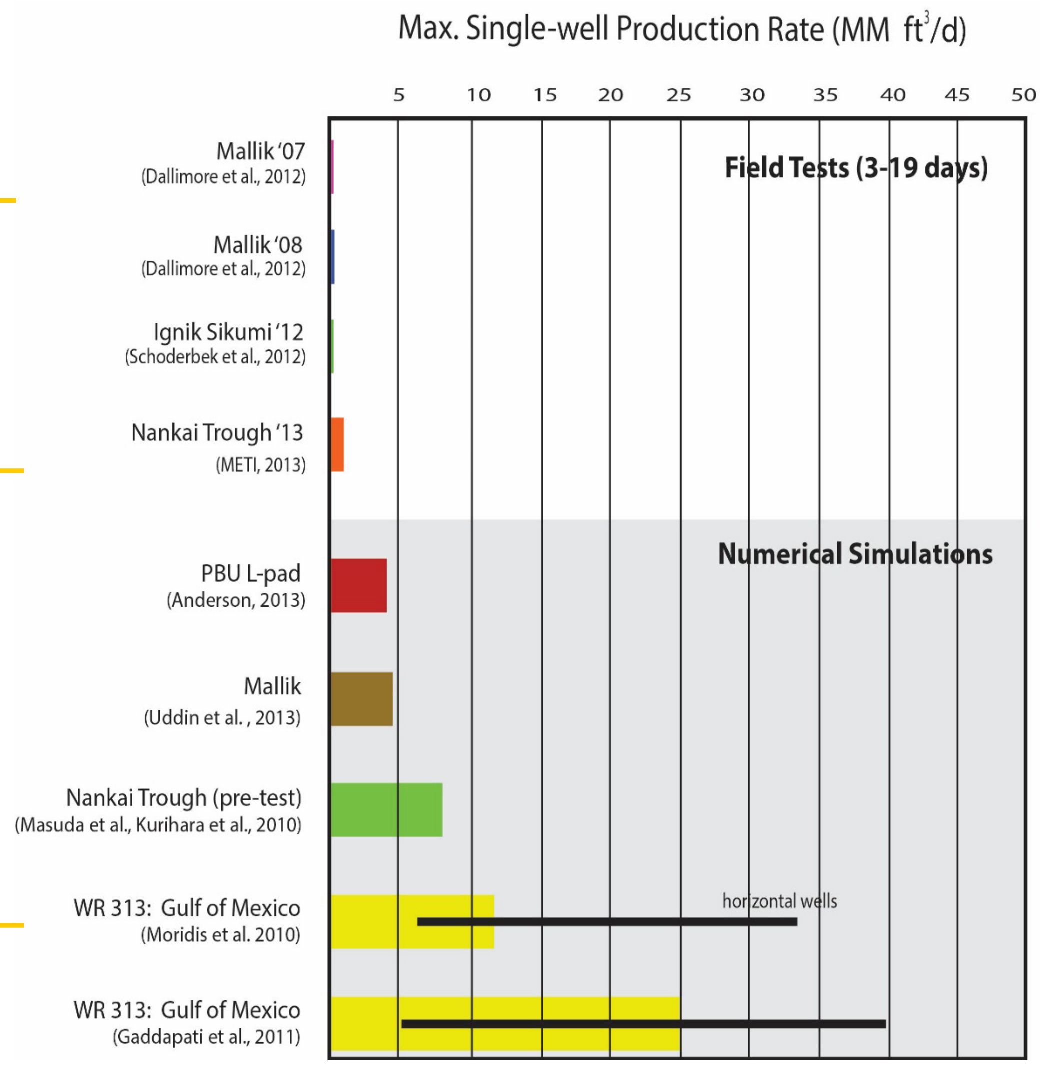
Gas Hydrate Production Rate

Comparison of Tests Results and Numerical Simulations

- **Field Tests**
  - Onshore 60 mscf/d
  - Offshore 700 mscf/d

- **Simulation - Onshore**
  - Onshore: up to 4 mmscf/d

- **Simulation - Offshore**
  - Offshore: up to 40 mmscf/d



Modified from Boswell

China (2017) Gas Hydrate Production Test

China's First Gas Hydrate Extraction Successful
19-May-2017
CGTN Editor: Liang Meichen ECNS App Download

China successfully extracted natural gas hydrate for the first time in the Shenhu area of the South China Sea on Thursday, China Geological Survey announced. China Geological Survey (CGS), under the Ministry of Land and Resources, was in charge of the natural gas hydrate extraction test project, which started on May 10 and lasted for seven days and 19 hours. The CGS extracted natural gas hydrate from mines in the Shenhu area of the South China Sea, drilling 203-277 meters below the depth of 1,266 meters. By 10:00 hr (0200 GMT) on Thursday, the accumulated gas output had surpassed 120,000 cubic meters. The highest output in one day is 35,000 cubic meters (1.2 mmcf/day), and the average output a day is about 16,000 cubic meters (0.6 mmcf/day).

Japan (2017) Gas Hydrate Production Test

Gas Production Test Under the Second Offshore Methane Hydrate Production Test was Restarted (Japan)
06-June-2017

The Agency for Natural Resources and Energy (ANRE*) has launched the Gas Production Test under the Second Offshore Methane Hydrate Production Test, commissioned to the Japan Oil, Gas and Metals National Corporation (JOGMEC), was once suspended, but the test was restarted and confirmed the production of natural gas. Since 04-May-2017, ANRE has been advancing a gas production test on the Daini Atsumi Knoll. On 15-May-2017, it was decided to suspend the test due to a significant amount of sand entering a gas production well. It has started preparatory work for conducting a gas production test at another production well for which different types of preventive measure against sand entry has been provided. The decompression work was started on 31-May-2017 and the natural gas production was confirmed on 05-June-2017. Gas production test will be continuously conducted by using the second production well until the late June.

****ANRE is part of the Ministry of Economy, Trade and Industry (METI).***

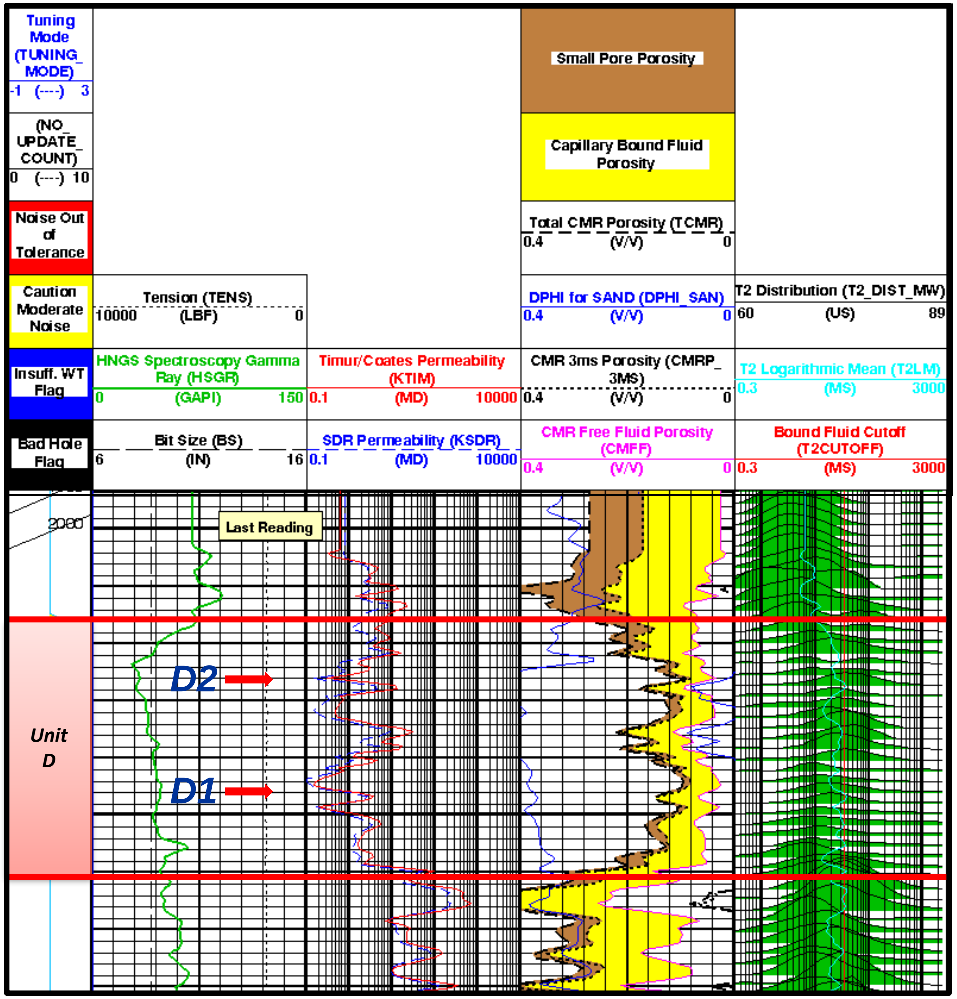
- **Alaska North Slope, USA**

  Alaska BP/DOE/USGS stratigraphic test

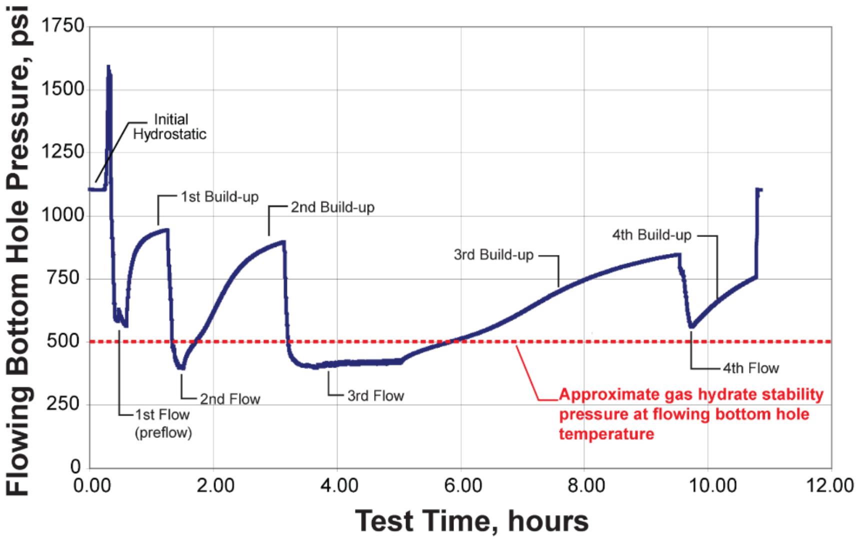
  Alaska ConocoPhillips/JOGMEC/DOE production test

Alaska North Slope – Mount Elbert Well

Reservoir Properties – Effective Permeabilities



Mount Elbert 1 – Unit D



Gas Hydrate Reservoir Properties

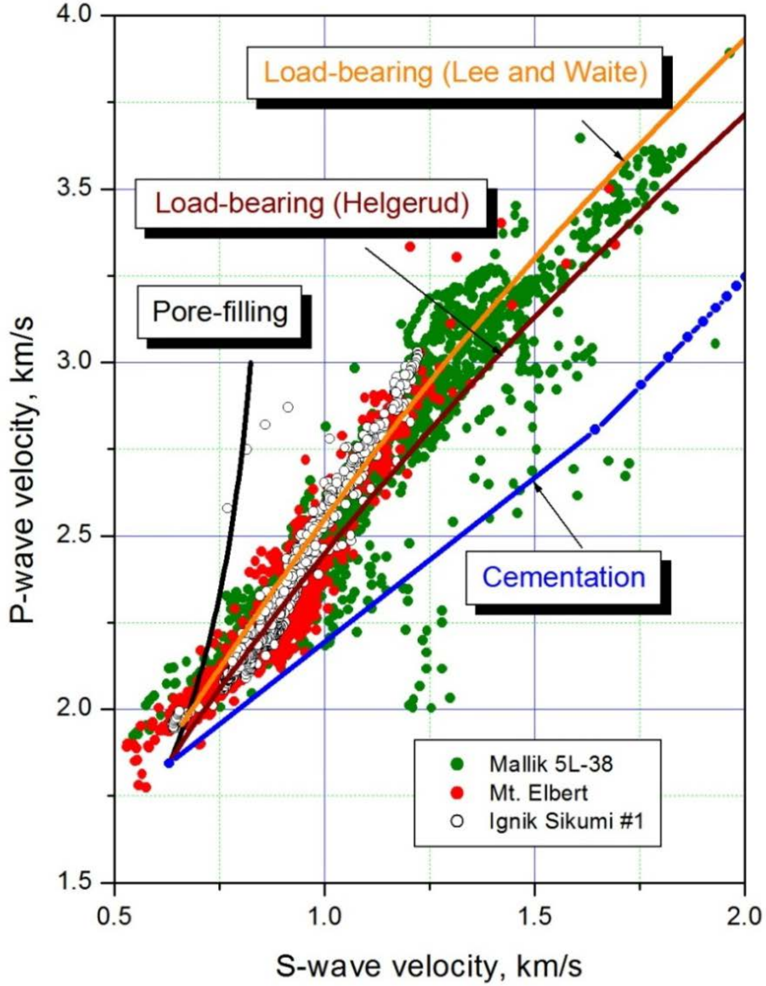
TC-SDR Effective Perm 0.1 - 1.0 mD

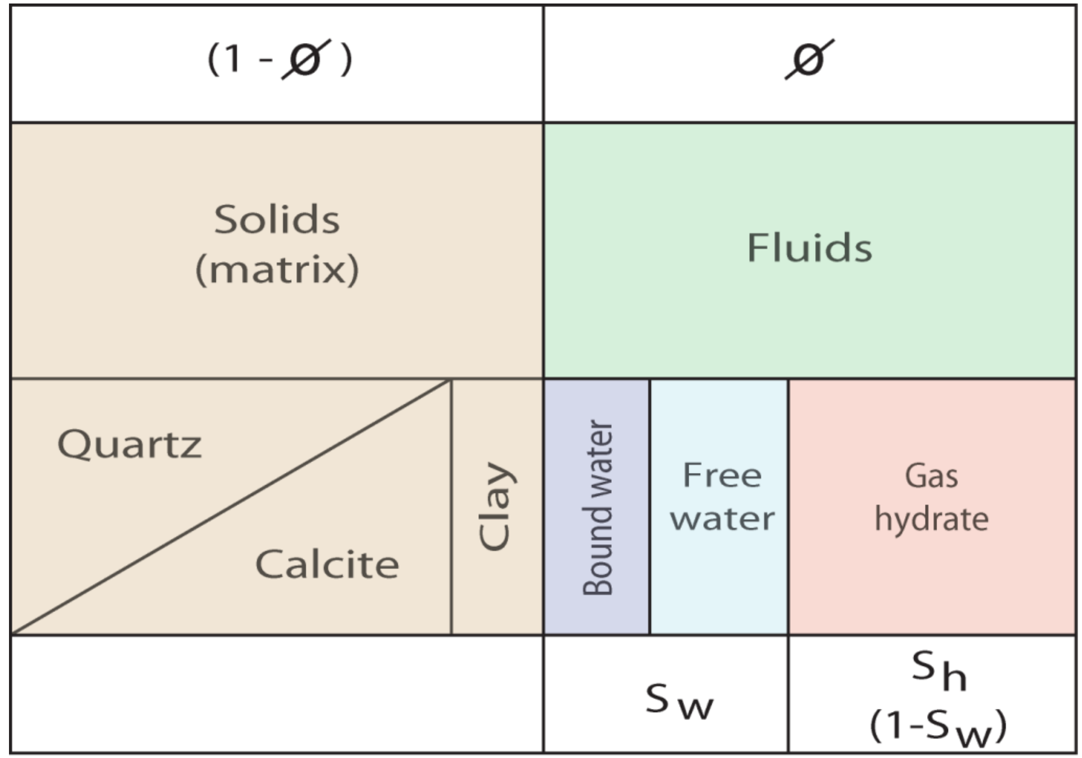
Sw 25% (15% free water, 10% bound)

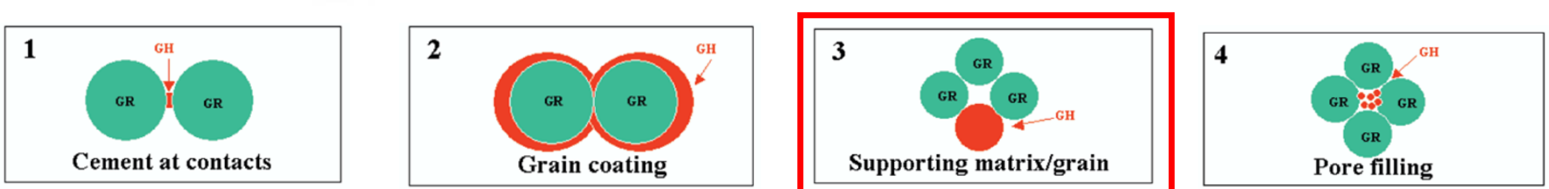
MDT Effective Perm 0.12 – 0.17 mD

Gas Hydrate Reservoir Models

Pore-Filling (load-bearing) Growth Habit



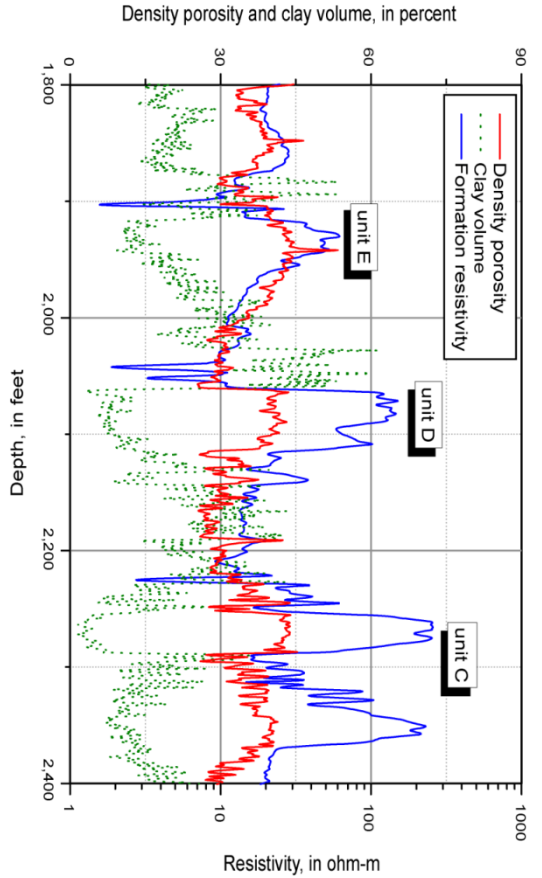


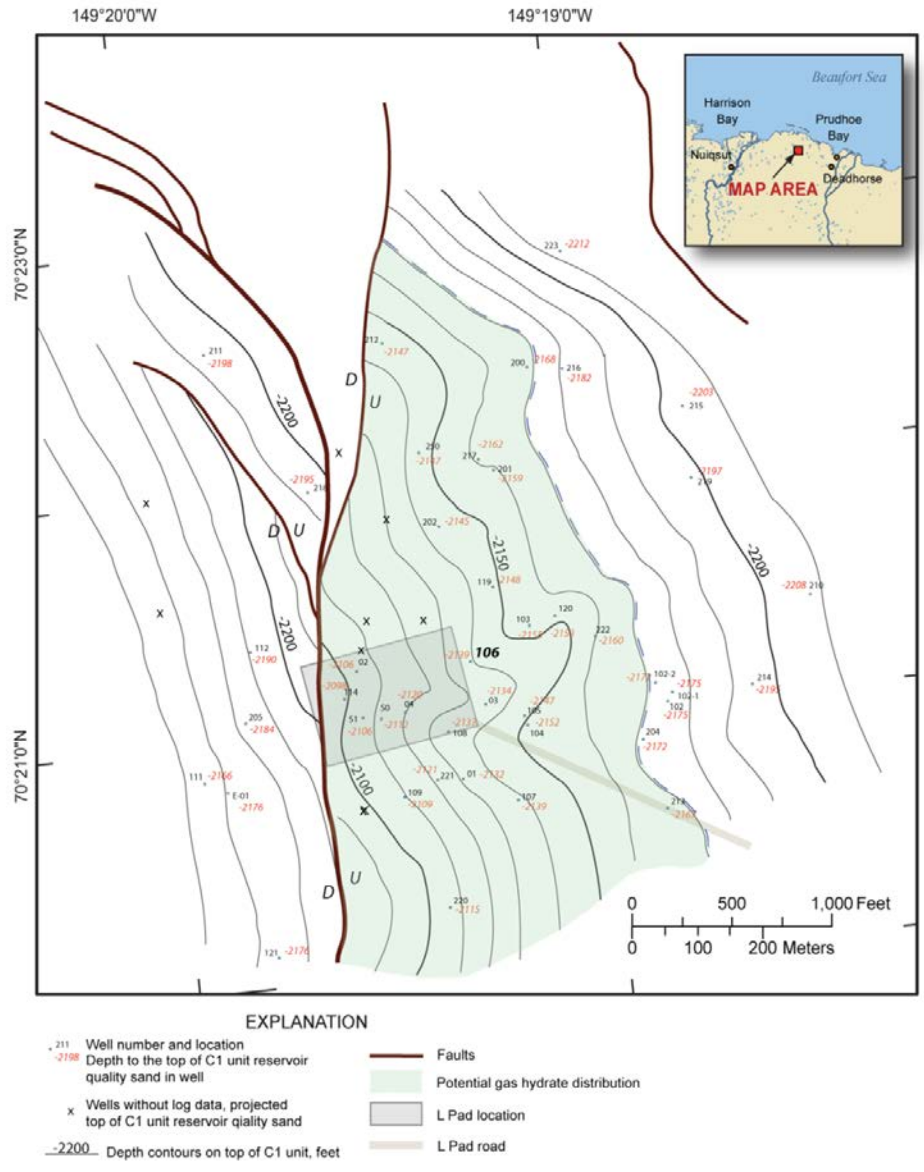


Gas Hydrate Production Model

PBU L Pad Gas Hydrate Accumulation

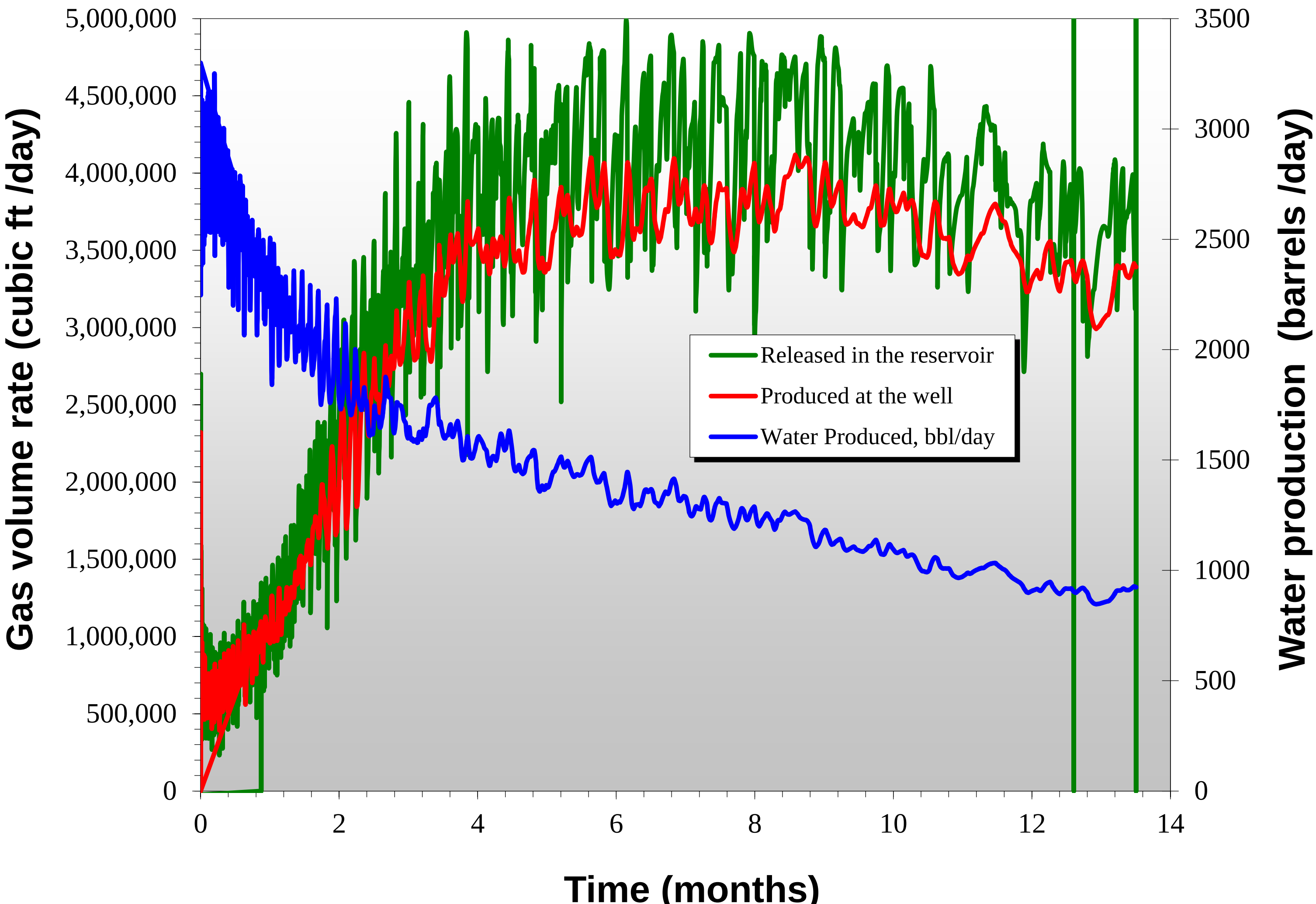
- ***PBU L Pad: Structure map on the top of Unit C***
- ***Minimal extent of gas hydrate occurrence***





Gas Hydrate Production Model

Shale Bounded Sand-Rich Unit – 180 Days



PBU L-Pad Unit C

Predicted Gas and Water Production

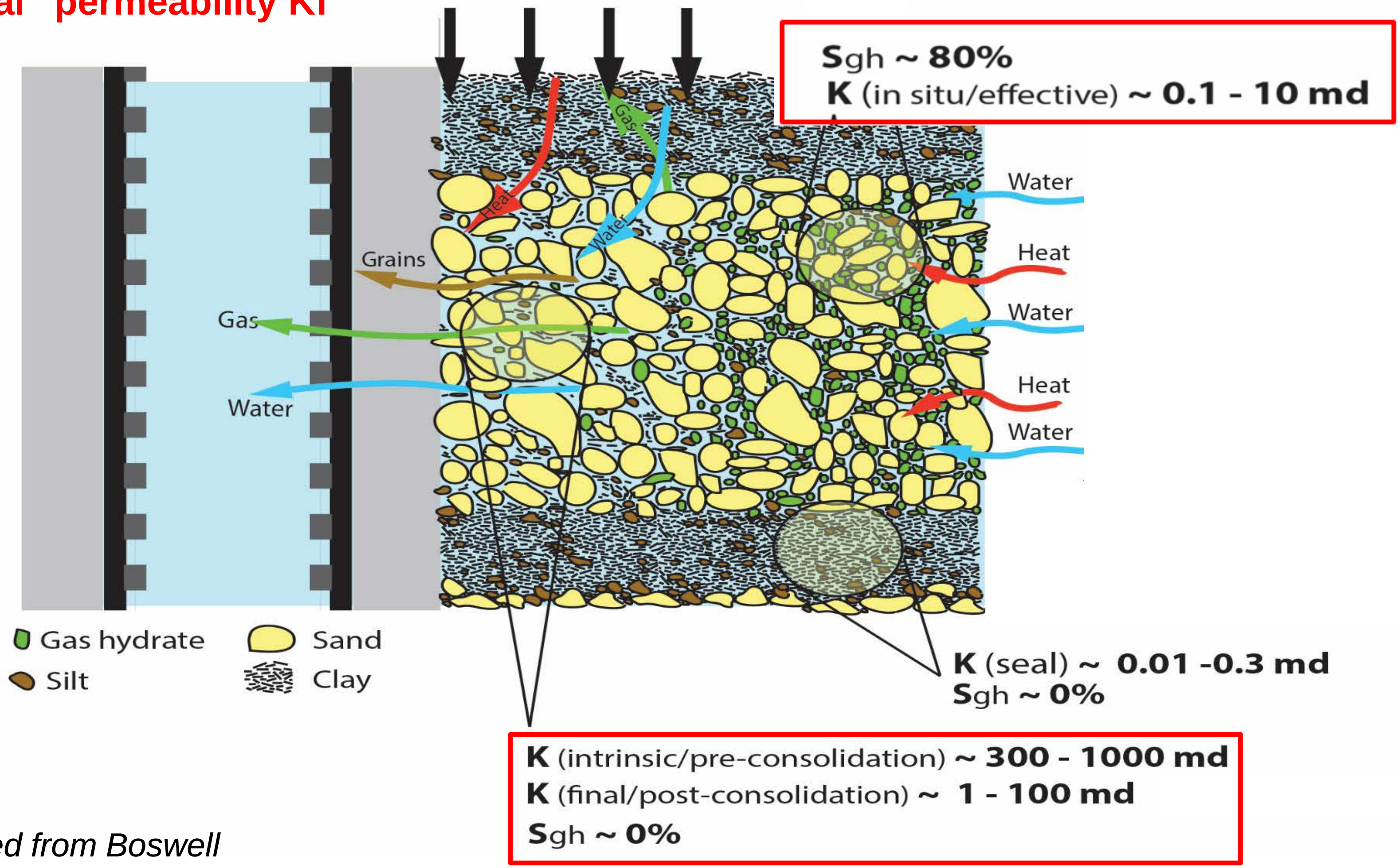
West Virginia University

Reservoir Properties

Pressure and Temperature Controls

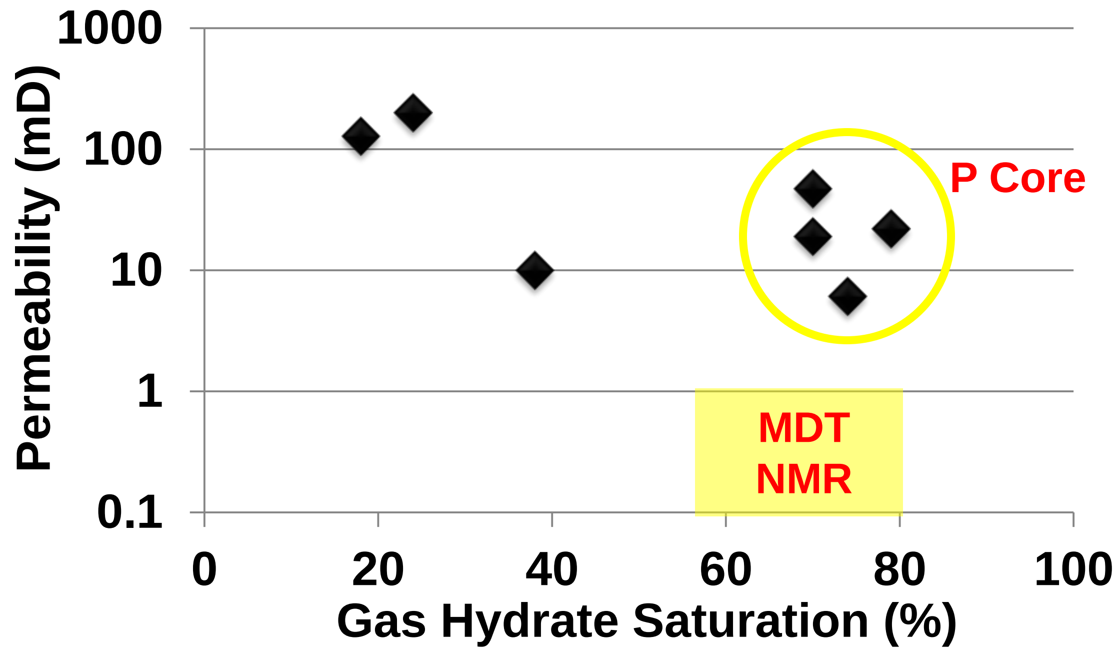
Reservoir Permeability (pressure) Controls
- **Intrinsic permeability Ki**
- **Effective permeability Ke**
- **“Final” permeability Kf**

Source of Heat
- **Conductive heat flow: Reservoir & bounding units**
- **Convective heat flow: Reservoir fluids**



Modified from Boswell

Nankai Trough
Gas Hydrate
Pressure Core Analysis



Effective Permeability Discrepancy

Pressure-core measurements (>10 mD)

MDT/NMR test and log analysis (<1.0 mD)

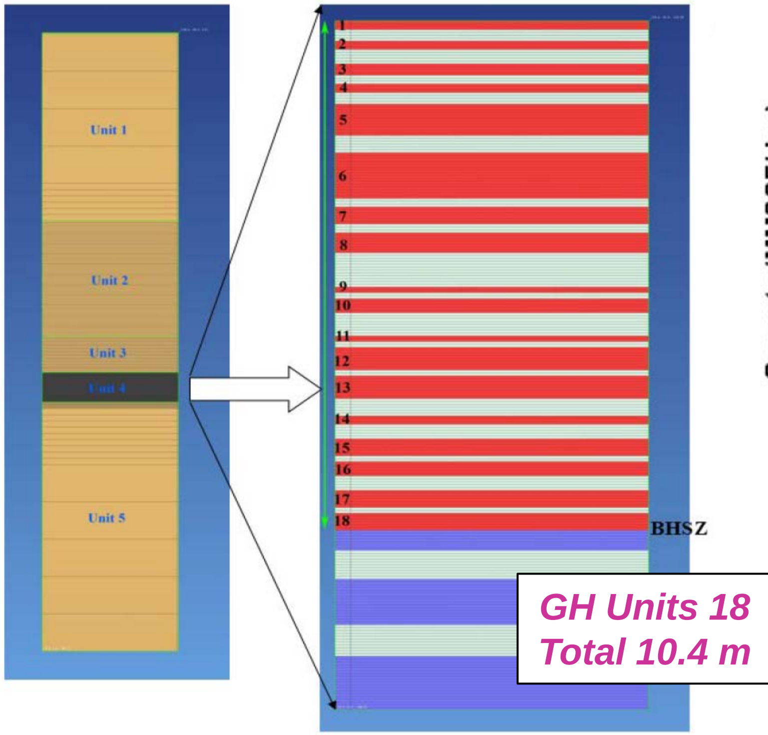
70	**19**	Priest
74	**6**	Santamarina
79	**22**	Yoneda

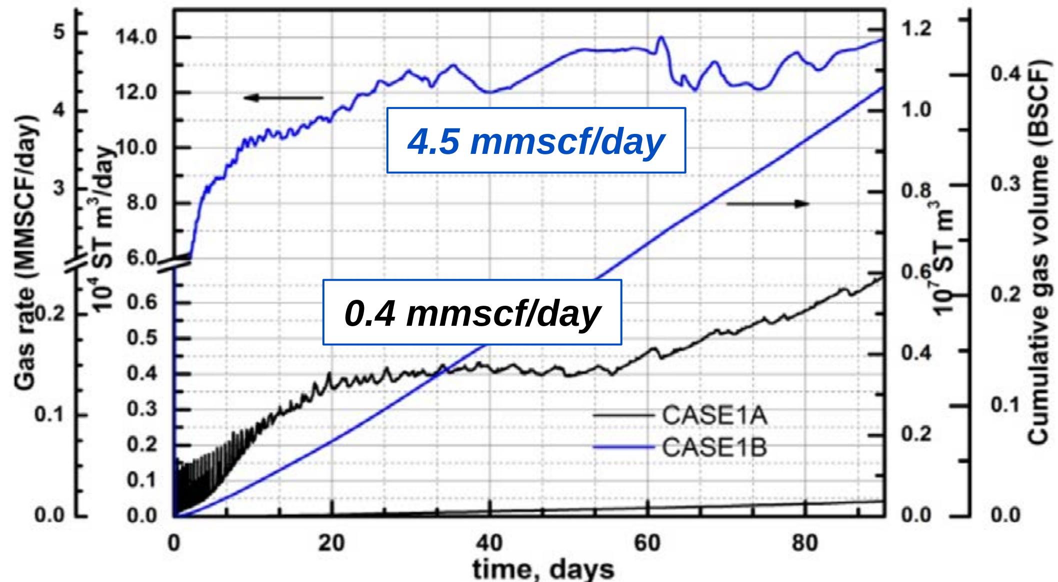
NMR log data 0.01-1.0 mD (Fujii et al., 2015)

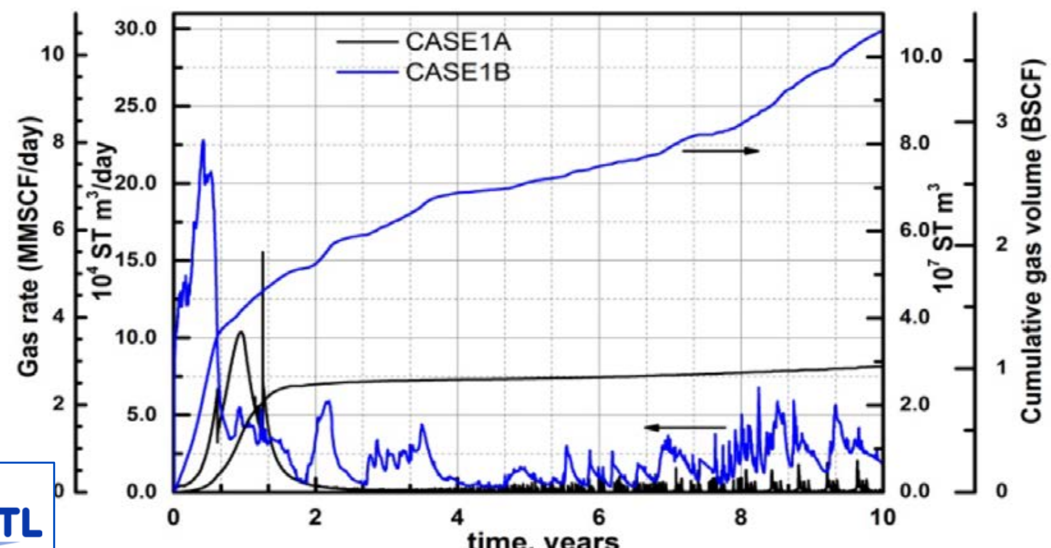
Pressure core analysis "several tens of mD" (Konno et al., 2015)

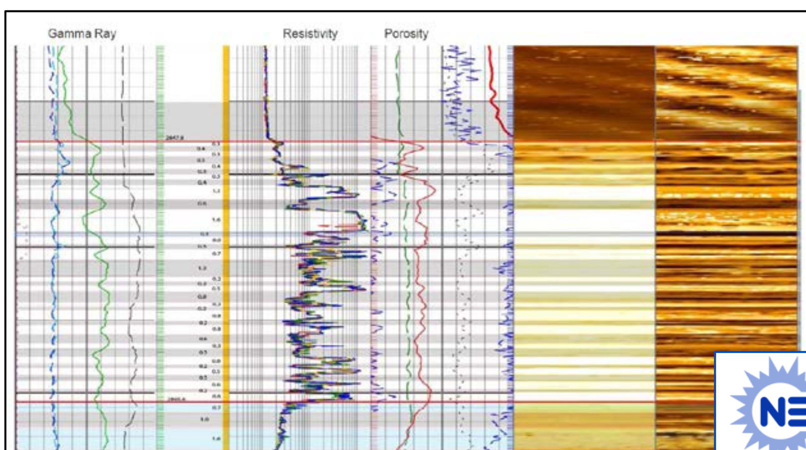
GH Production Modeling – Permeability Uncertainty

Case 1A – Ke 0.1 md *vs.* *Case 1B – Ke 10 md*

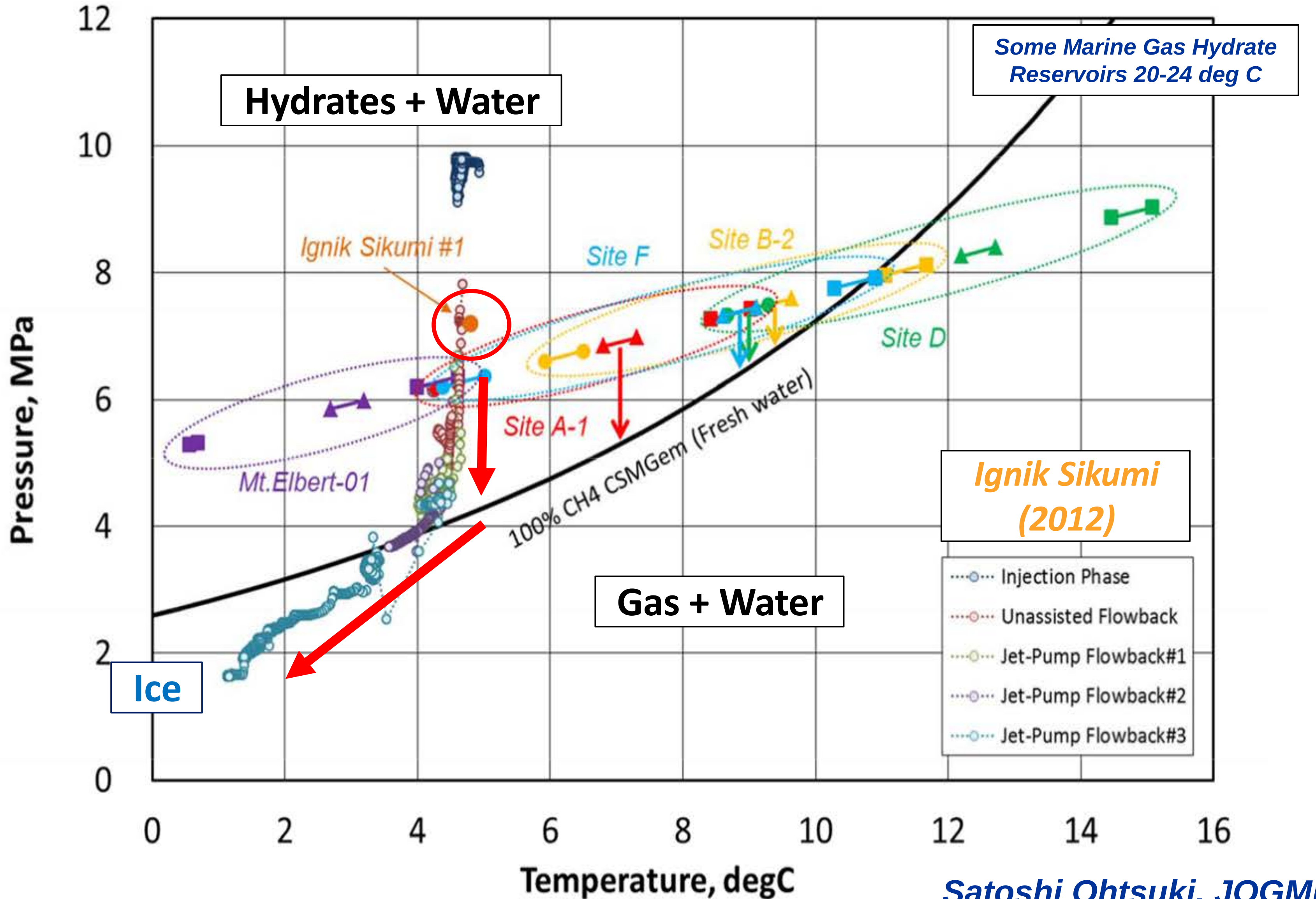






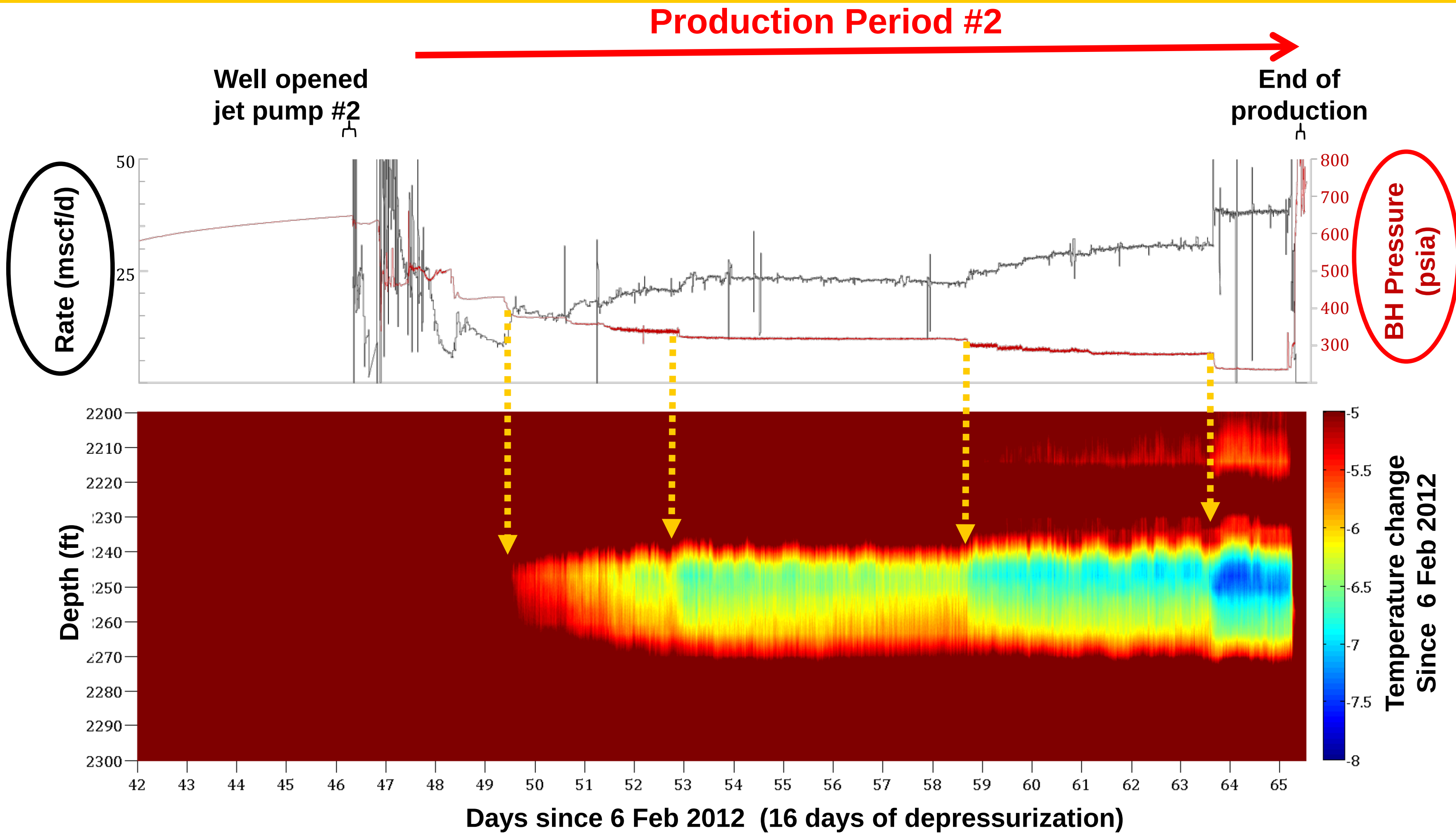


Iġnik Sikumi – Depressurization Test Phase



Satoshi Ohtsuki, JOGMEC

Iġnik Sikumi – Depressurization Test Phase

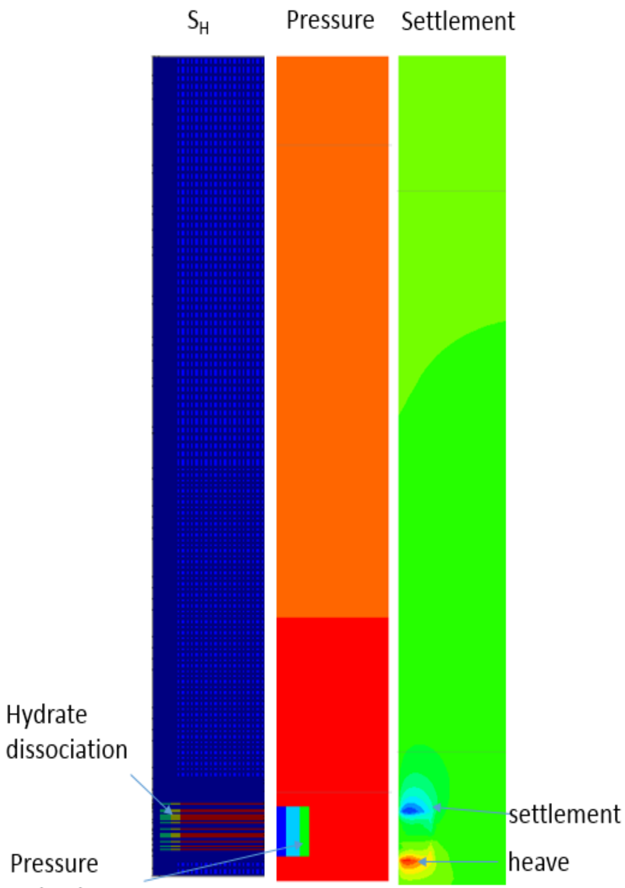


Pressure – Production Rate - Temperature

Geomechan. & Sand Production Modeling

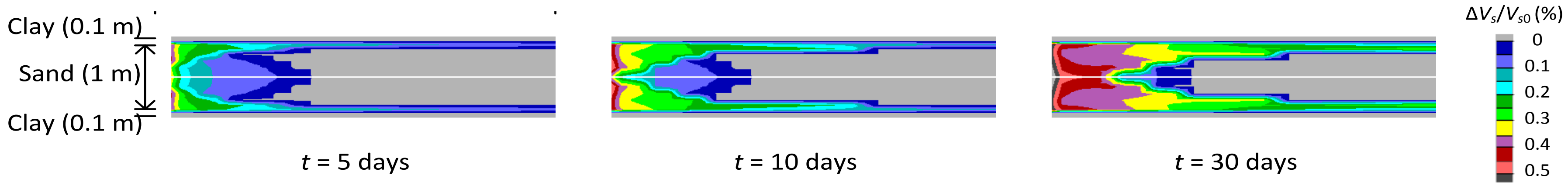
In Support of NGHP-03 Planning

- **NETL and U. Pittsburgh (J-S Lin) -- Geomechanical Modeling**
- **Two approaches: TplusH+FLAC3D**
  - Coupled approach → maximum settlement of 135 cm; maximum heave of 20 cm
  - De-coupled approach → maximum settlement of 140 cm; maximum heave of 45 cm



Typical Study Scenario

- **NETL and Rensselaer Polytechnic Institute (S. Uchida) -- Sand Production Modeling**
  - Sgh = 80%; T= 19.4 C; P = 28.5 Mpa with drawdown to 20 Mpa



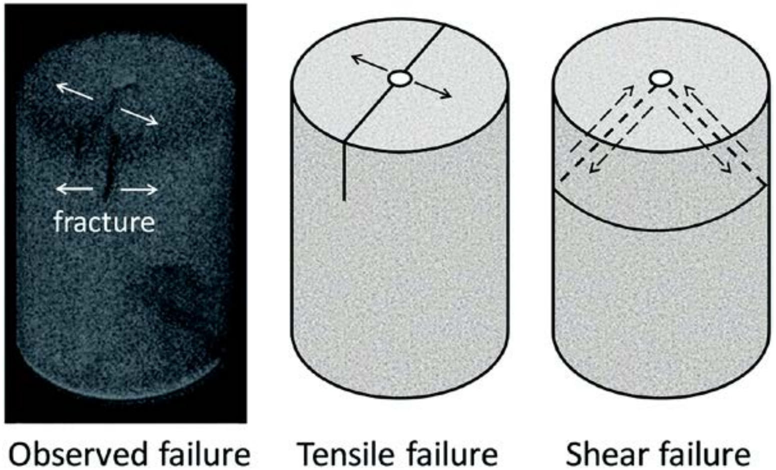
t = 5 days *t* = 10 days *t* = 30 days

Gas Hydrate Production

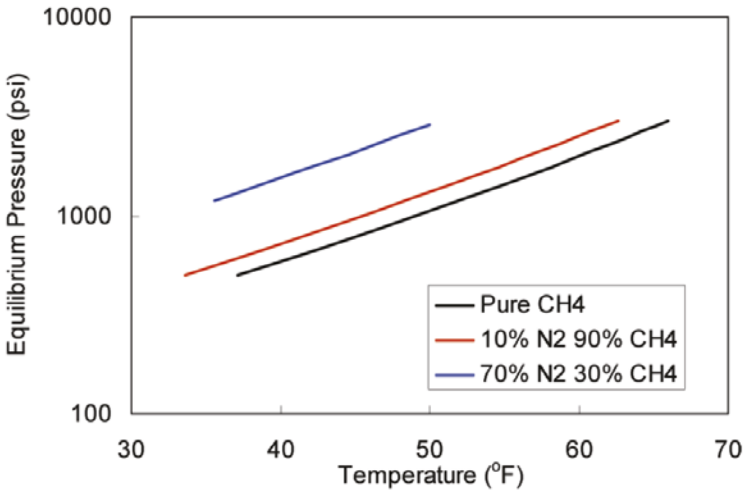
"Conventional" and Enhanced Methods

- **Proven Gas Hydrate Production Technologies**
  - Temperature: Thermal methods
  - Pressure: Depressurization methods
  - Chemical Injection: Methanol, salt
  - Chemical Injection: C02-CH4 Exchange (sequestration)
- **Untested Gas Hydrate Production Technologies**
  - Horizontal Completions
  - Hydraulic Fracturing
  - Enhanced Permeabilities: N2, Methanol

Hydraulic Fracturing in Methane-Hydrate-Bearing Sand, By Konno et al, 2016



Hydrate Plug Dissociation via Nitrogen Purge: Experiments and Modeling, By Panter et al, 2011



Gas Hydrates from Resources to Reserves

GH Reserves

GH Resources

GH Reserves

Motivations

Production Technology

GH Resources
Where, How, Why

Development Scenarios

Assumed similar to the evolution of other unconventional resources – possibly not

Japan Nankai Trough Model: Standalone production with limited to no infrastructure

USA Gulf of Mexico (mature development area): Make use of existing infrastructure and backfill declining conventional production

Local Market Drivers: Example, Alaska North Slope fuel gas needs and conventional oil reservoir pressure maintenance

Gas Hydrates from Resources to Reserves

GH Reserves

GH Resources

GH Reserves

Motivations

Production Technology

GH Resources
Where, How, Why

Current Challenges

Further development of GH reservoir models, from pore scale micromechanical and hydrodynamic models to full field models

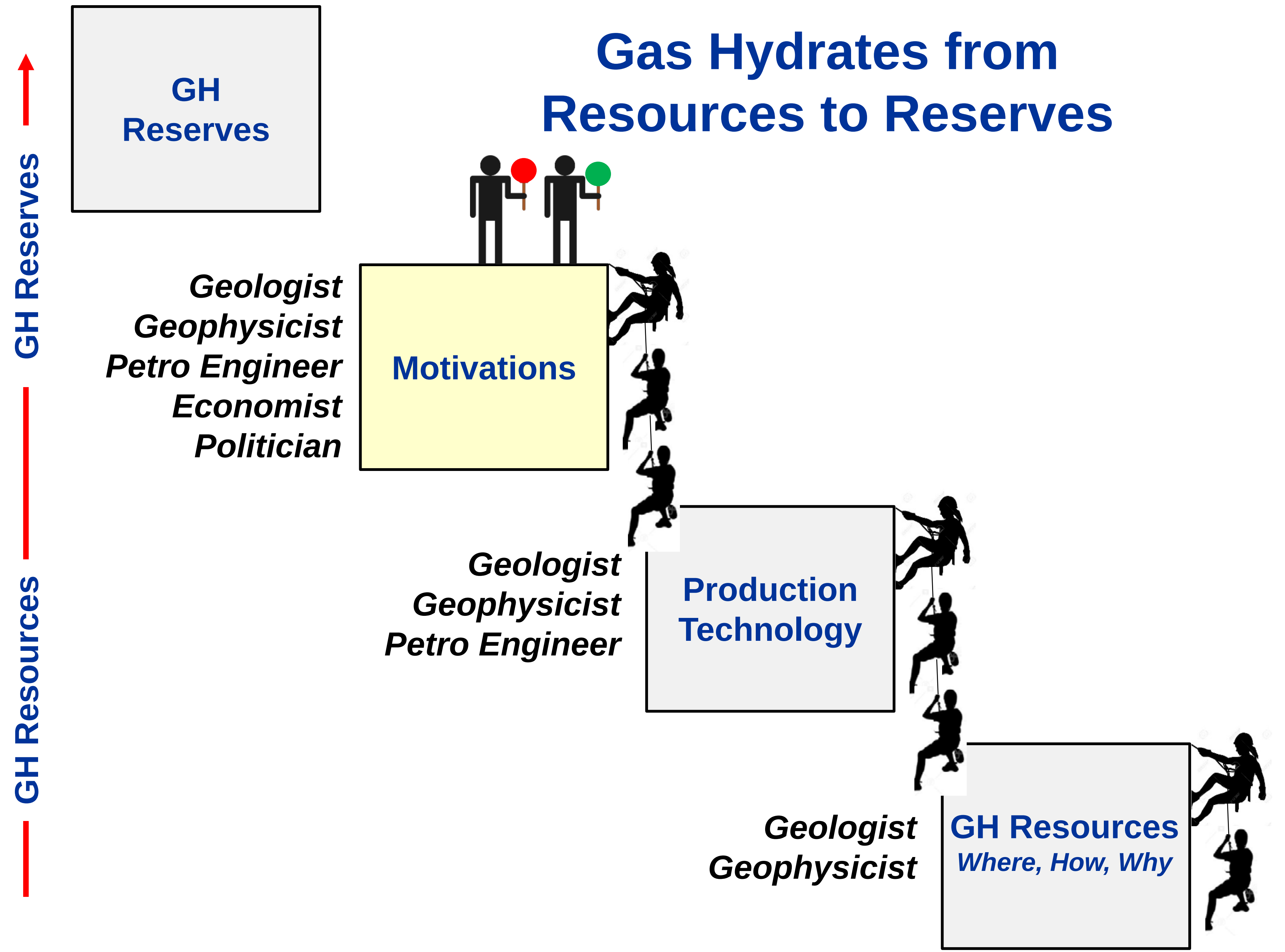
Laboratory, modeling, and field scale analysis of GH-bearing reservoirs responses to production and applied stimulation methods

Advance completion technologies (horizontal, multi-lateral completions, etc.) and artificial production stimulation have shown promise but not field tested

Identify and assess potential drilling and completion concerns associated with the production of GH

The impact of production on GH reservoir and seal petrophysical and mechanical properties is incomplete

Consensus: Required investment in field production testing and related environmental studies


Gas Hydrates from
Resources to Reserves
GH Reserves
GH Resources
GH
Reserves
Geologist
Geophysicist
Petro Engineer
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Geophysicist
GH Resources
Where, How, Why

GH Resources → GH Reserves

GH Reserves

- Japan (MITI/JOGMEC): Commercial production by 2023 to 2027
- India (MoP&NG): Commercial production by 2020
- SBC Energy Institute: Economic production of GH in the next 10-20 years
- Consensus: Industry experts say that commercial gas hydrate development could be possible after 2030. Smaller scale output could be possible as early as 2018 (associated with production testing)

Motivations

- **Global Competition: Emergence of other gas and energy resources**
- **In most cases, unknown resource volume and unproven production technology**
- **Commercialization of GH at about twice the cost of conventional gas (maybe)**
- **Special National interest and local drivers**
- **Impact of taxation and climate change policies (royalties, carbon tax, etc)**
- **Industry interest and investment**

Production Technology

- Field testing and modeling have confirmed the viability of GH depressurization
- Important advances in petrophysical and mechanical properties analyses
- The further development and calibration of advance GH reservoir models
- Assessing the impact of GH production on reservoir and mechanical properties
- Investment in field testing and environmental studies (but limited)

GH Resources

Where, How, Why

- Development of the GH Petroleum System concept
- More than 25 major GH geoscience related projects/expeditions since 1995
- Advances in field data acquisition and analysis
- Advances in GH laboratory and modeling studies
- Geologic based GH assessments (in-place, technical recoverable, reserves est.*)*

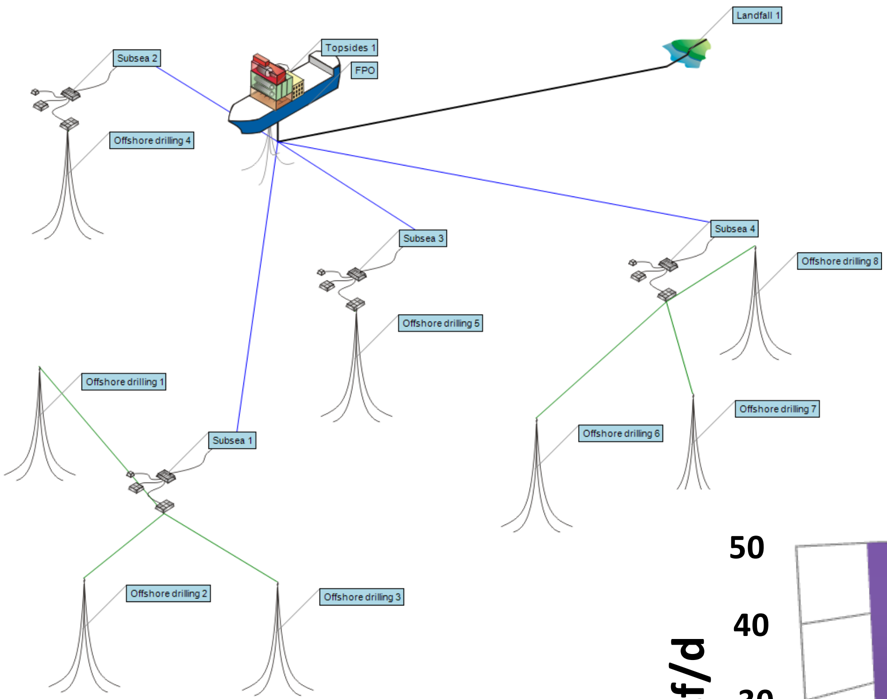
Development of Deepwater Gas Hydrates
Steve Hancock, XtremeWell Engineering

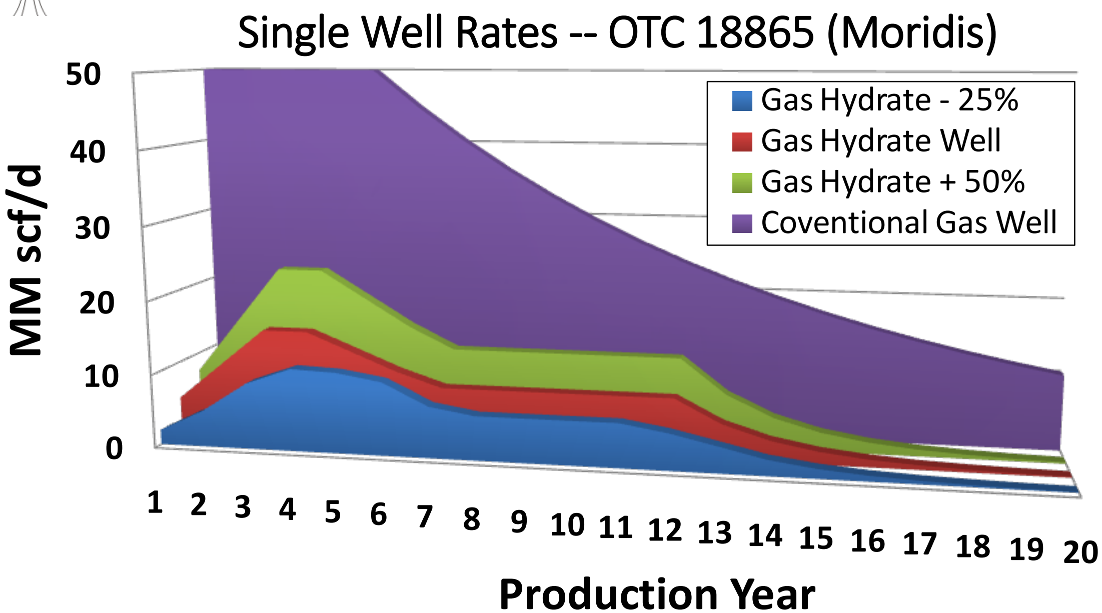
XtremeWell Engineering

Gas Hydrate Production Considerations

- Gas production rate
- Water production rate
- Operating pressure
- Hydrate/freezing control
- Sand control
- Mechanical stability, subsidence, etc
- Production forecasts based OTC 18865 (Moridis)
- Depressurization only, 500 MMscf/day capacity
- Subsea development with multiple 6 well clusters, 5000 ft water depth, 8200 ft TVD well depth

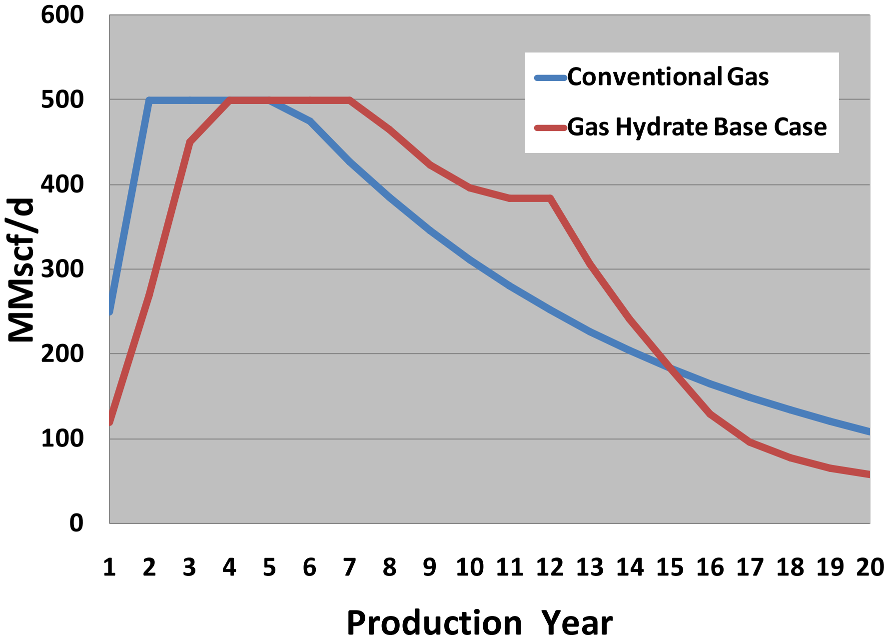
Gas Production Forecast and Development Plan



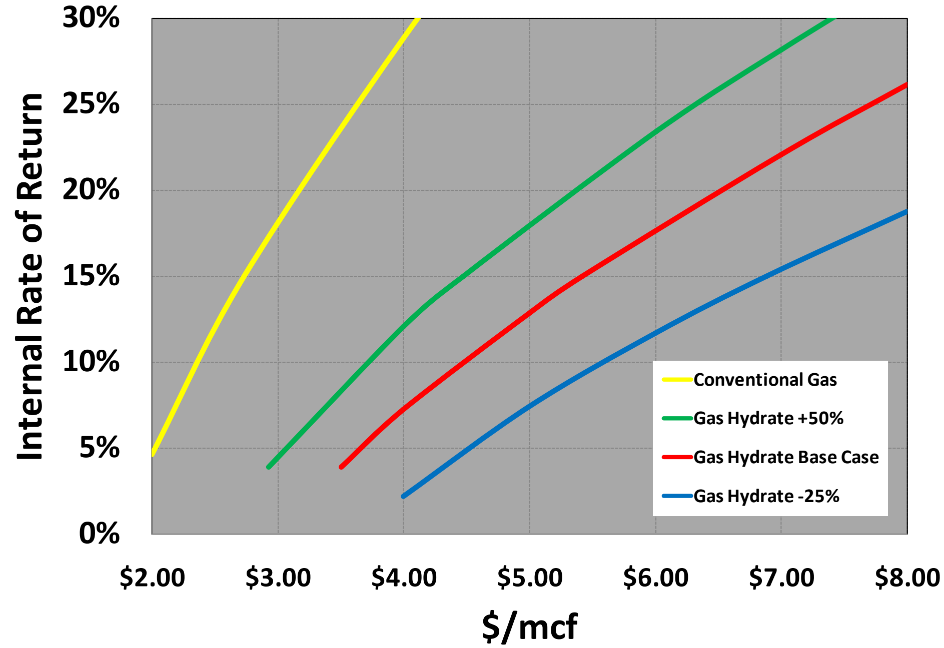


Gas Production Forecast and Economic Analysis

Field Production – Total Gas



Internal Rate of Return



*Significant financial rewards can be realized if gas hydrate well productivity can be brought in line with "typical" high rate deepwater wells – **50+ MMscf/d***

Note: no royalties, pre-tax

Gas Hydrates from Resources to Reserves

GH Reserves

GH Resources

GH Reserves

Motivations

Production Technology

GH Resources
Where, How, Why

Economics

Global Competition: Emergence of other gas and energy resources

In most cases, unknown resource volume and unproven production technology

Occurrence in deep water and Arctic environments – high cost, large operators, return on investment challenging (competition)

Limited economic forecasting has shown commercialization of GH is possible at about twice the cost of conventional gas production under similar conditions (as bench marked at $3.00 US/MBtu)

US: Henry H. price $2.00-4.00 US/MBtu; Residential price $9.00-18.00 US/MBtu
Net import 2015 3.8 tcf (14% of consumption)

Japan: LNG landed price $7.60 US/MBtu; Residential gas price $43.05 US/MBtu
Last 10 year, increase in consumption from 3.0 to 4.7 tcf of gas per year

India: LNG landed price $7.45 US/MBtu
Last 10 year, increase in consumption from 2.5 to 4.5 tcf of gas per year
80% of India's energy is imported

Gas Hydrates from Resources to Reserves

GH Reserves

GH Resources

GH Reserves

Motivations

Production Technology

GH Resources
Where, How, Why

Special National Interest and Local Drivers

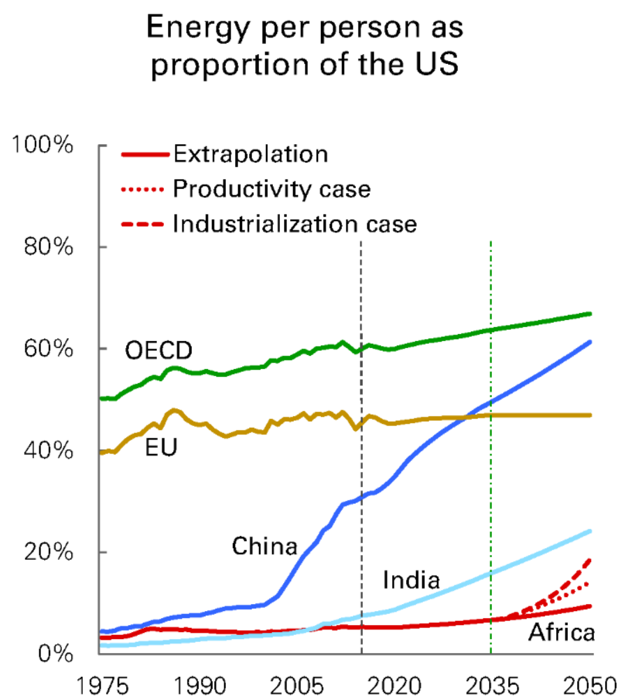
Impact taxation & climate change policies (royalties, Carbon-tax)

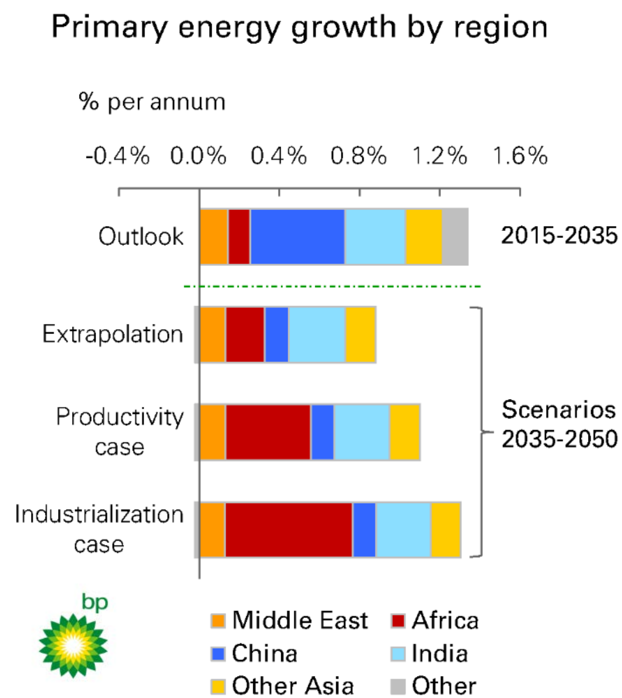
Establishment of government and industry partnerships

Development of purpose built GH development systems

Alaska North Slope fuel gas & pressure maintenance

Availability of other energy resources (market distance/stability)





Gas Hydrates from Resources to Reserves

GH Reserves

GH Resources

GH Reserves

Motivations

Production Technology

GH Resources
Where, How, Why

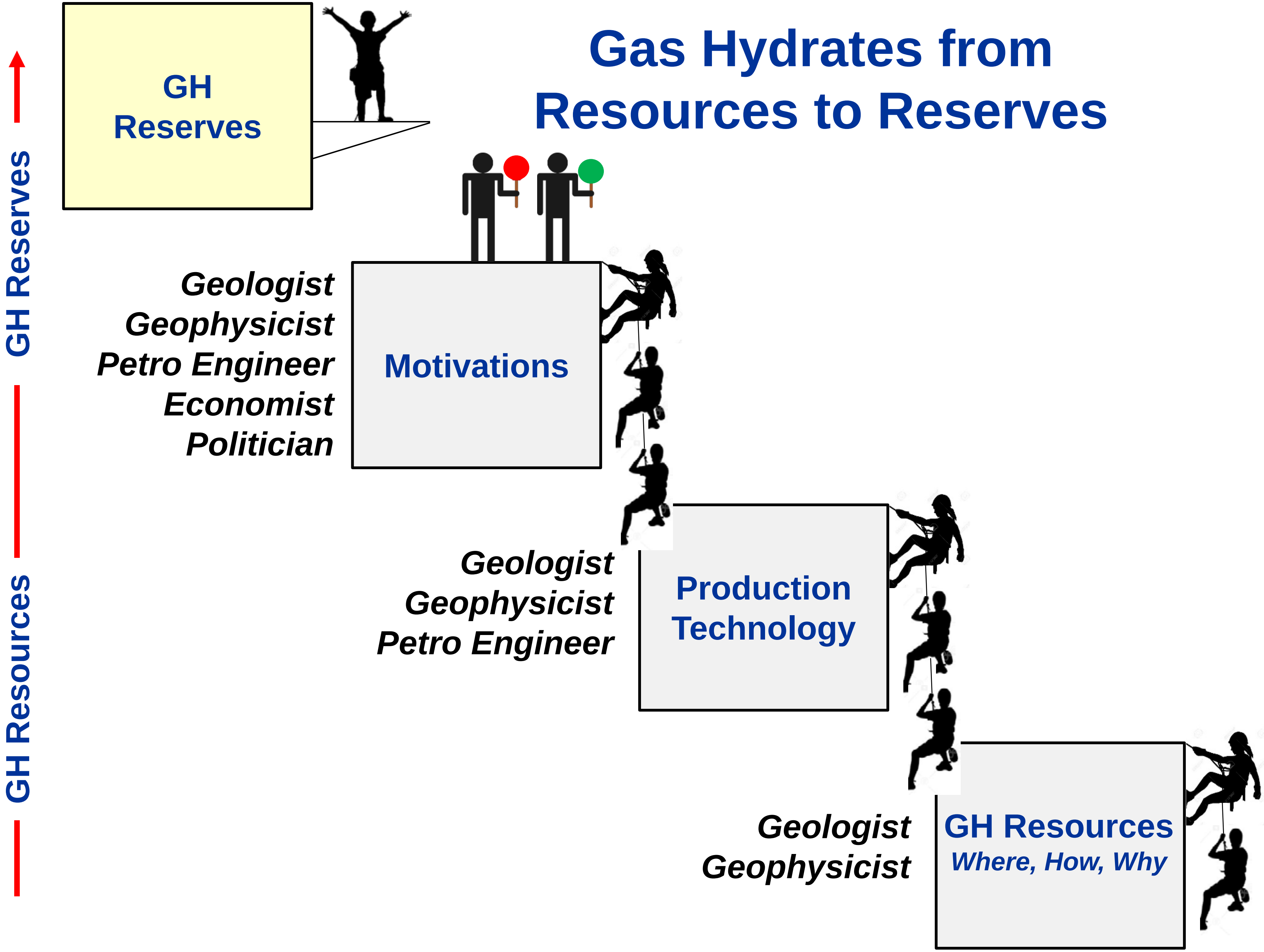
Political/Regulatory Policy

Taxation policy and royalties that could stimulate GH interest and investment

Climate policy (carbon tax and other related incentives):

Hesitation to invest in a new source of fossil fuel that emits greenhouse gases; however, more gas added to the energy mix could reduce the overall carbon footprint associated with global energy consumption

GH could provide a bridging energy more environmentally acceptable than coal or oil on the way to a carbon-free world based on alternative energy solutions



Gas Hydrates from
Resources to Reserves
GH
Reserves
GH Reserves
GH Resources
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Geophysicist
Petro Engineer
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GH Reserves | GH Resources

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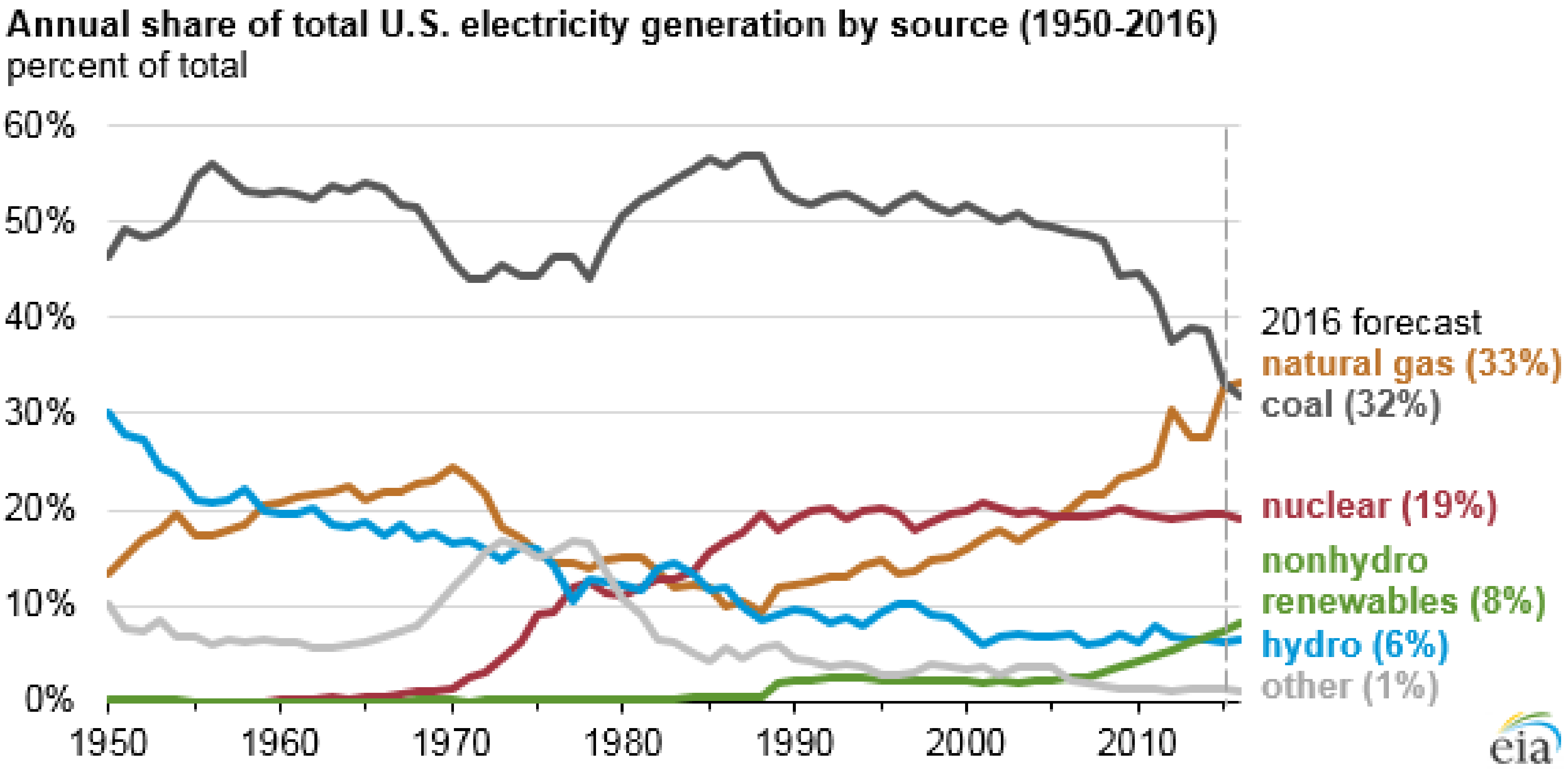
- Geologic based GH assessments (in-place, technical recoverable, reserves est.)

Energy Resource Displacement



Coal being Displaced by Gas and Renewables

Energy Resource Displacement

Competition Production Rate and Well Cost

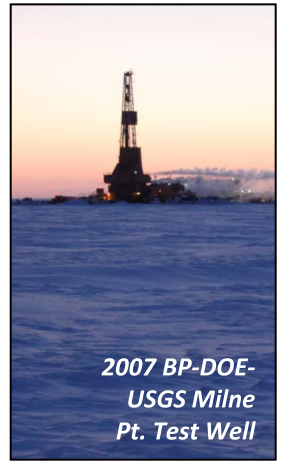
Resource	Production Rate mscf/day (x1,000)	Well Cost USD (x1,000)
Coalbed Methane	500	1,000
Shale Gas Barnett	500-2,000	3,000-4,000
Shale Gas Woodford	500-3,500	4,000-7,000
Conventional Alaska NS	7,500	5,000-15,000
Conventional Deepwater		
-GOM 1,500-5,000 ft	90,000	>50,000
-GOM 5,000-7,500 ft	100,000	>100,000
Gas Hydrate Modeling		
-Alaska NS 5-6 °C	700	5,000-8,000
-Alaska NS 10-12 °C	5,000	5,000-8,000
Gas Hydrate Modeling		
-Offshore	5,000-15,000	>20,000

Need to reduce development/production cost or increase production rate.

Summary - Technical

GH Prospecting - Characterization - Production Technology

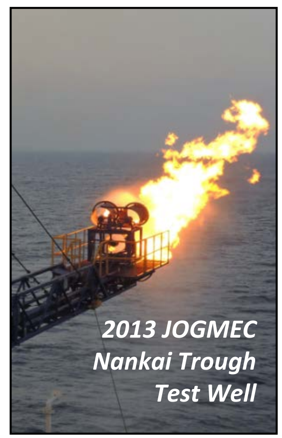
- **Application of Petroleum System Concept**
  - Support of gas hydrate prospecting and assessments
- **Target Resource is Substantial**
  - 40,000 tcf globally
  - 10,000 tcf US offshore (BOEM)
  - 85 tcf technical recoverable Alaska (USGS)
- **Base Production Technology Demonstrated**
  - Four successful scientific field tests, additional tests in China, Japan, and India
  - Base technology (depressurization) identified
  - Modeled rates encouraging (up to 40 mmscf/d)
  - Recovery should be high (60-80%)
  - Long-term test required; Alaska opportunity in progressing
- **Wells Will be Challenging**
  - Cold reservoirs, low-pressure, etc.
  - Produced water & subsidence concerns
  - Environmental impact monitoring



2007 BP-DOE-USGS Milne Pt. Test Well

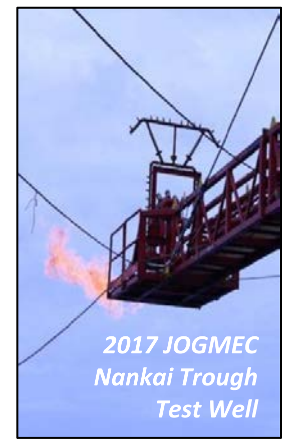
2007/08 JOGMEC NRCan Mallik Test Well

2011/12 CP-DOE-JOGMEC Prudhoe Bay Test Well



2013 JOGMEC Nankai Trough Test Well

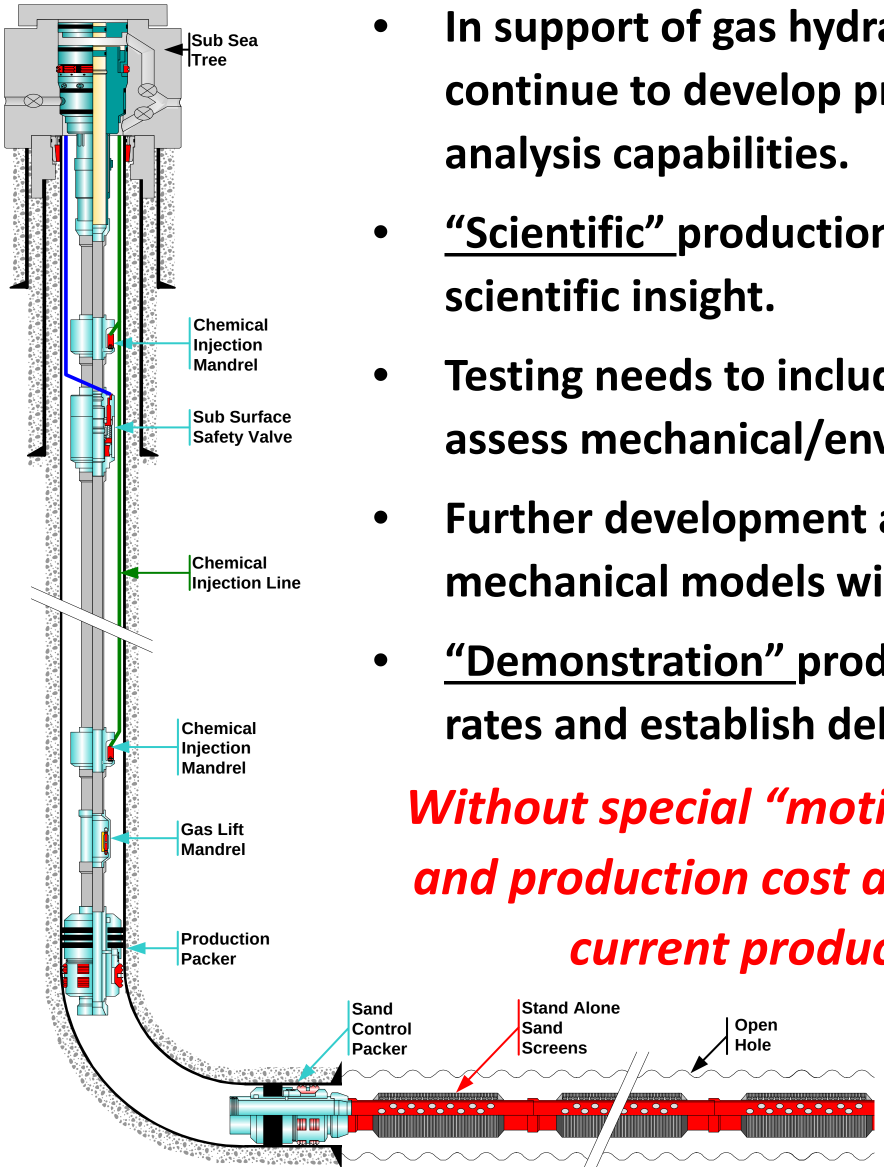
2017 CGS South China Sea Test Well



2017 JOGMEC Nankai Trough Test Well

Summary - Challenges

Evolution from a Gas Resource to a Gas Reserve



- **In support of gas hydrate production modeling and testing efforts, continue to develop pressure coring equipment and pressure core analysis capabilities.**
- **<u>"Scientific"</u> production/mechanical testing designed to maximize scientific insight.**
- **Testing needs to include advance monitor programs to identify and assess mechanical/environmental response/impacts.**
- **Further development and calibration of gas hydrate production and mechanical models with results from field testing and pressure cores.**
- **<u>"Demonstration"</u> production/mechanical tests designed to maximize rates and establish deliverability.**

Without special "motivations" will need to reduce development and production cost and/or increase production rates based on current production-mechanical modeling results.

Hancock et al., 2008

Primary Gas Hydrate R&D Issues

Operational/Natural Geohazards

1. Gas hydrate formation in production/well intervention equipment?
2. Surficial hydrate hazards to sea-floor structures?
3. “Conventional” well drilling/production in areas of gas hydrate?
4. Role of gas hydrate in large-scale mass wasting events?

Global Environment

1. Hydrate linkages to biological communities?
2. Can hydrate destabilization cause sea-floor instability?
3. How does hydrate mediate global carbon cycling over long time-scales?
4. What is the present/near-term future response of hydrate to ongoing global climate change?

Energy Resource Potential

1. What types of deposits are the feasible targets, and what are the volumes?
2. How can they be found?
3. Can they be produced at viable rates?
4. What are the environmental impacts and how can they best be minimized?

ICGH9 TOPICAL SESSIONS

1. Gas Hydrate Fundamentals
2. Gas Hydrates in Nature
3. Energy Recovery
4. Climate Change and Geohazards
5. Flow Assurance

SELF SERVING REQUEST

Our Charge

How does the presentation I am listening to and my own research contribute to our understanding of the geologic, engineering, environmental, economic, political, and other factors that control the ultimate commercial production of gas hydrates?

ICGH9 TOPICAL SESSIONS

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2. Gas Hydrates in Nature
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