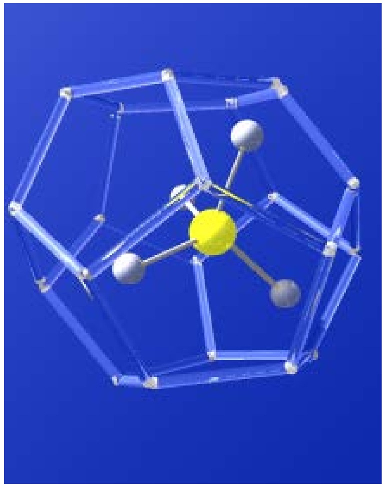
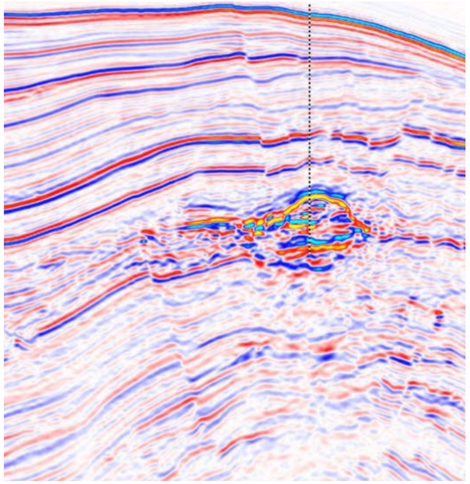



Gas Hydrates

Update on International Activities

Timothy S. Collett
U.S. Geological Survey

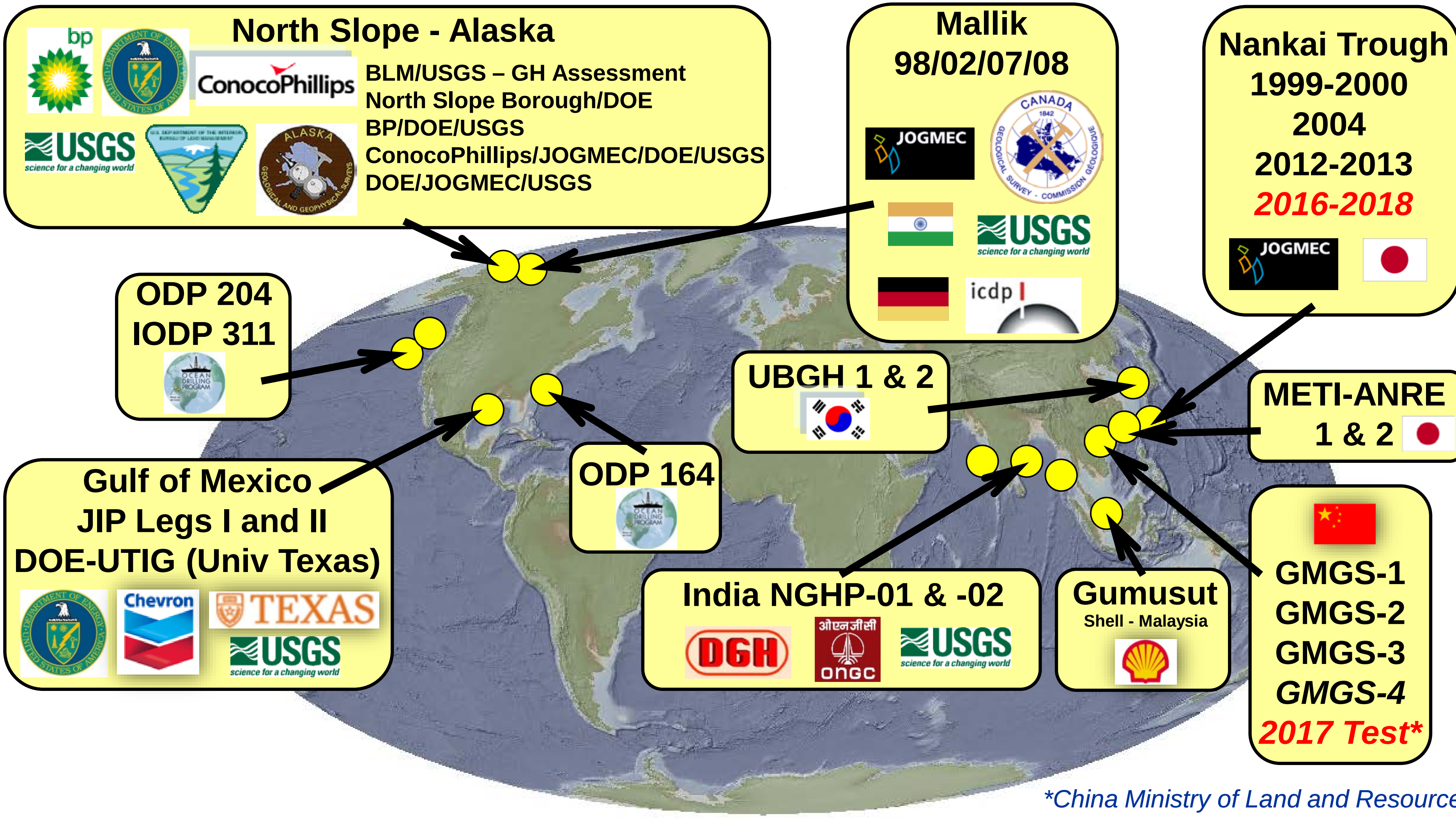
Methane Hydrate Advisory Committee Meeting
March 1, 2018

USGS
science for a changing world

Briefing Outline

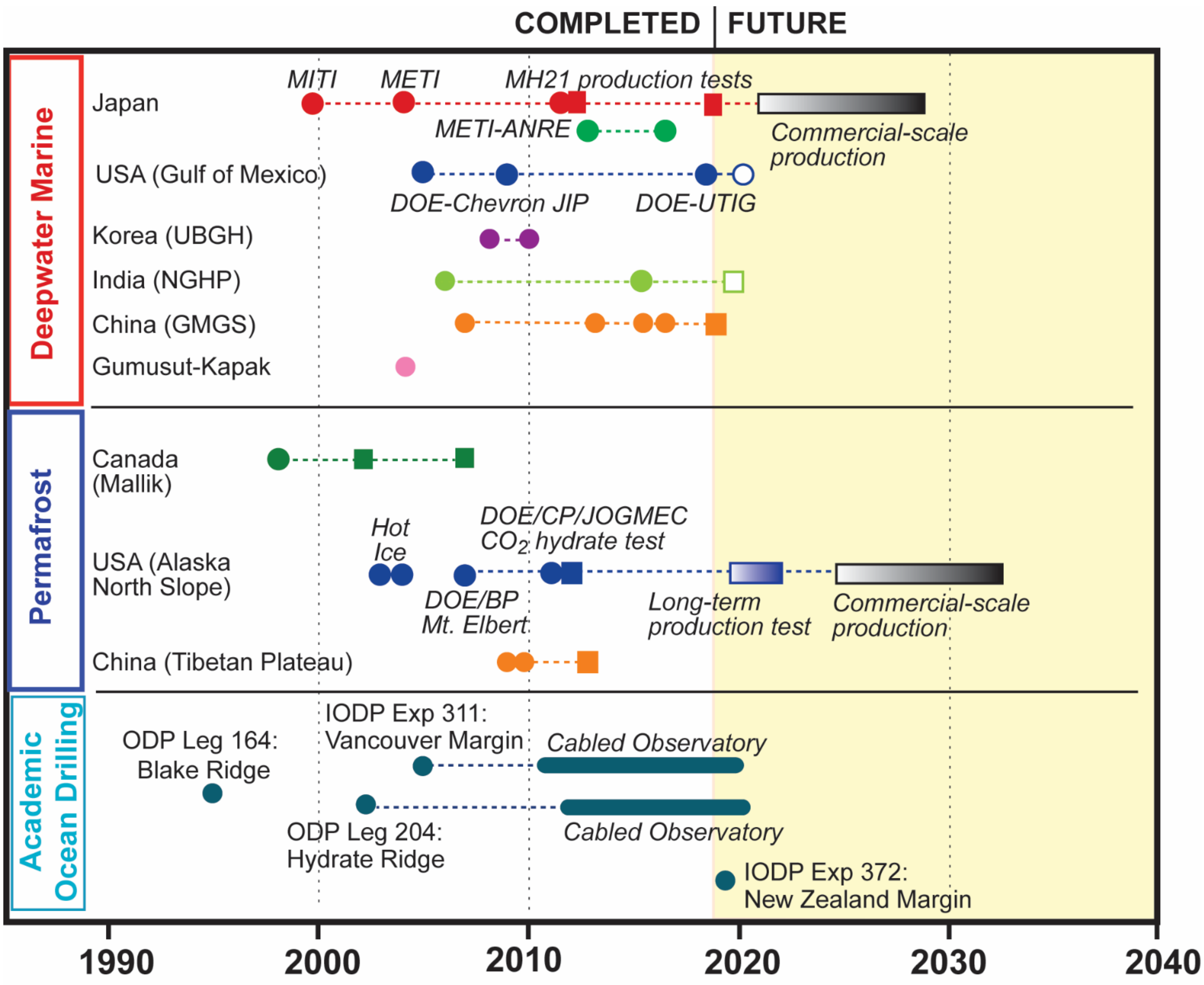
1. Gas hydrate scientific and industry drilling
2. Gas hydrate resource to reserves?
3. International gas hydrate projects
   - Japan
   - India
   - Republic of Korea
   - China
4. Additional international gas hydrate projects
5. Gas hydrate production testing and modeling
6. Integration gas hydrate reservoir data
7. Summary

Gas Hydrate Scientific and Industry Drilling



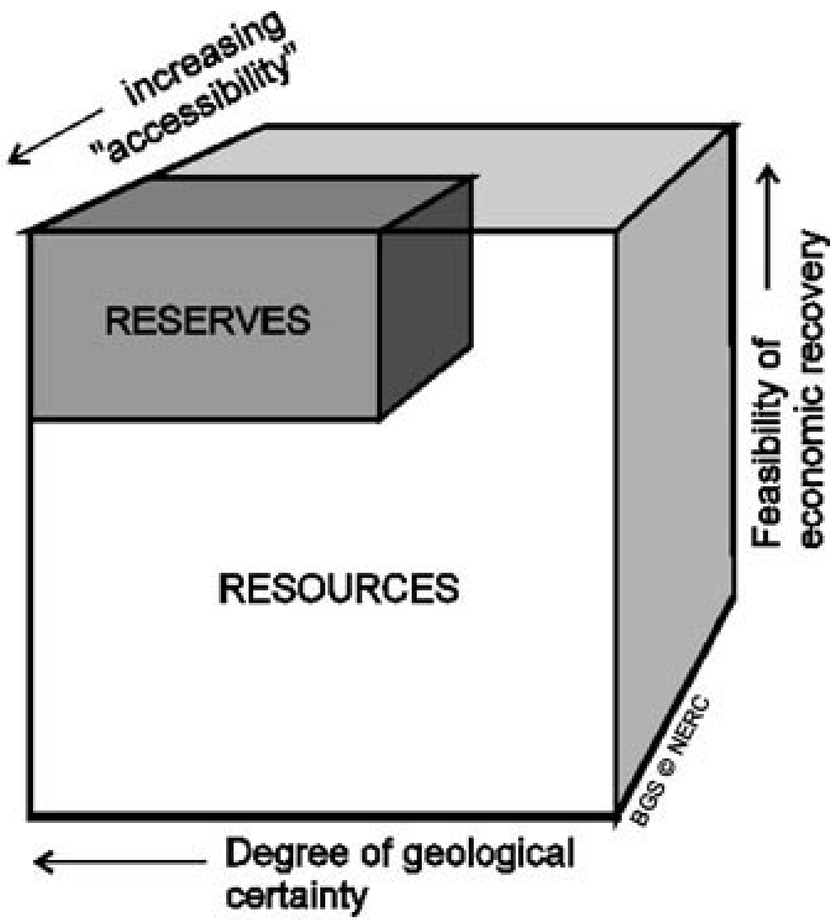
*China Ministry of Land and Resources

Gas Hydrate Scientific and Industry Drilling



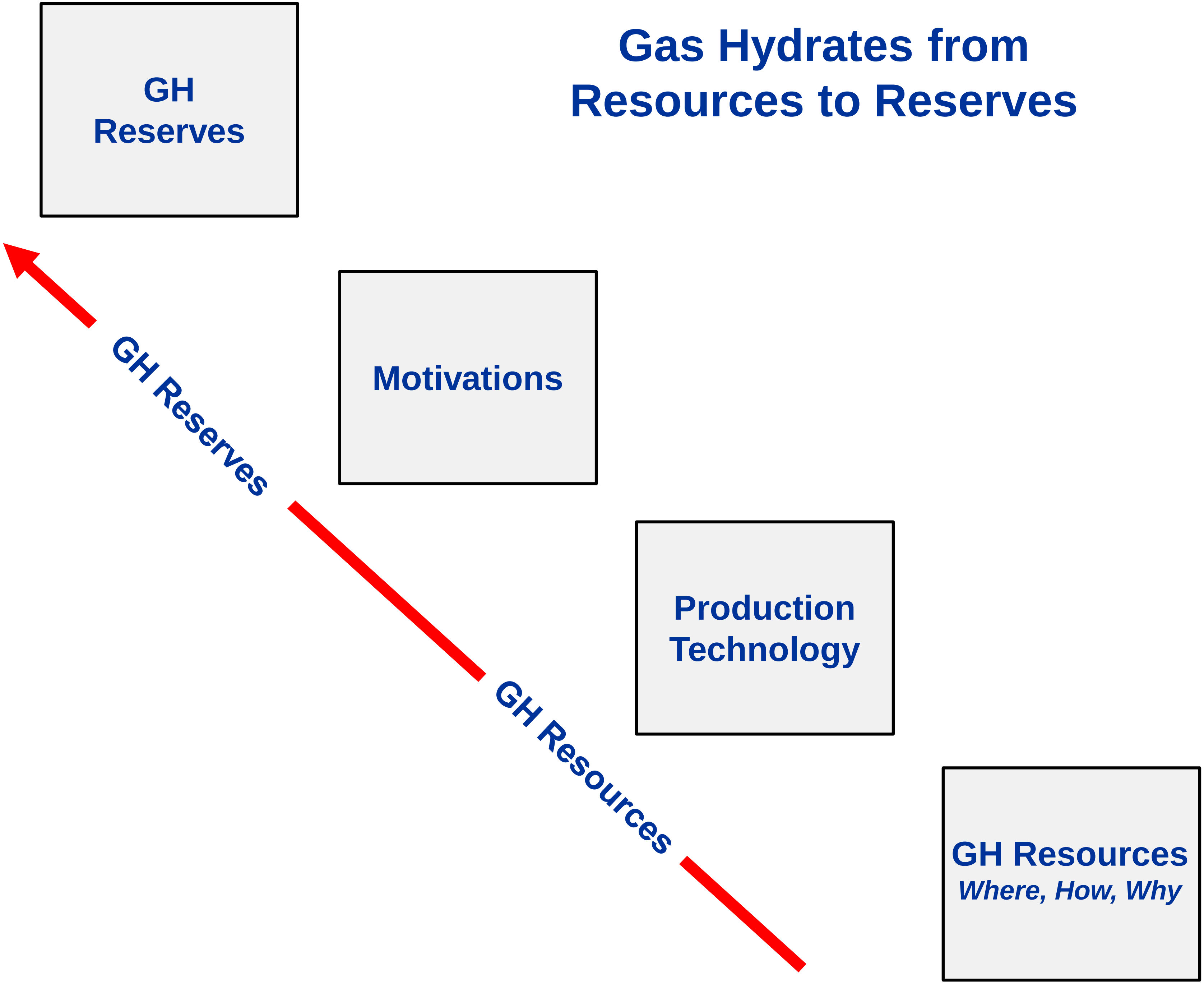
Gas Hydrate Resource Assessments

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 Reserves

Motivations

Production Technology

GH Resources

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

__Economics__

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

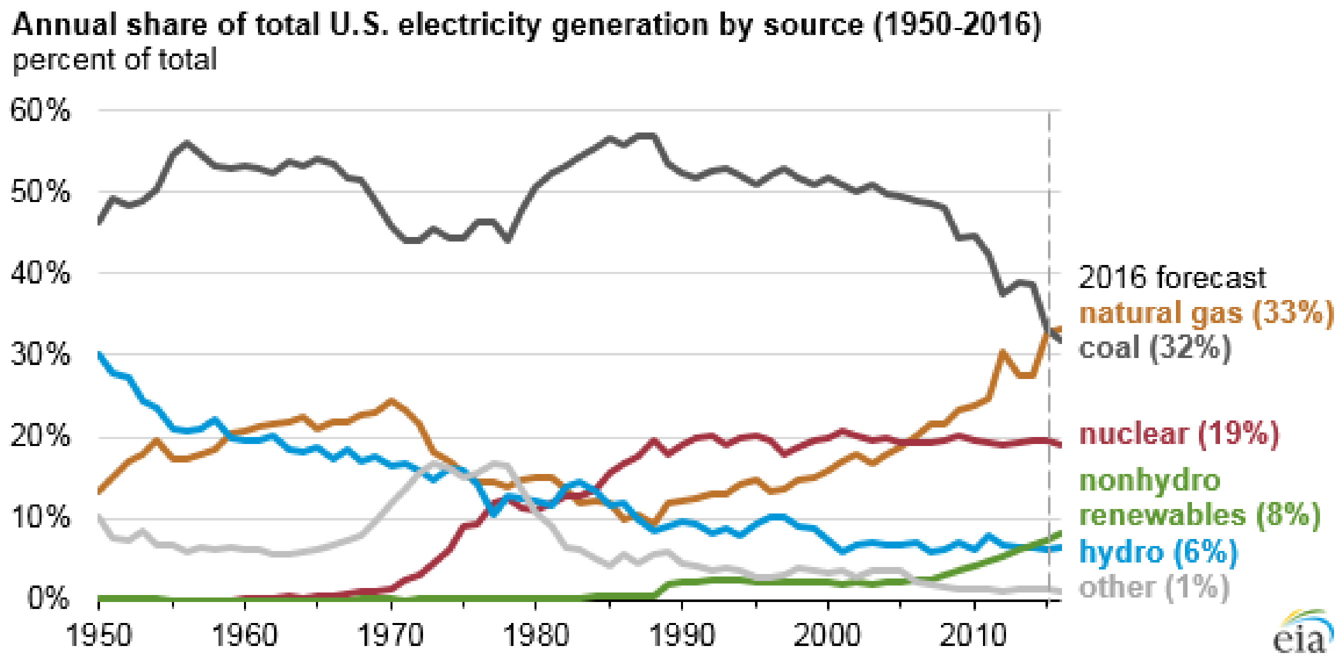
Motivations

Production Technology

GH Resources
Where, How, Why

Economics

Global Competition: Emergence of other gas and energy resources



Coal being Displaced by Gas and Renewables

GH Reserves

GH Resources

GH Reserves

Motivations

Production Technology

GH Resources
Where, How, Why

Gas Hydrates from Resources to Reserves

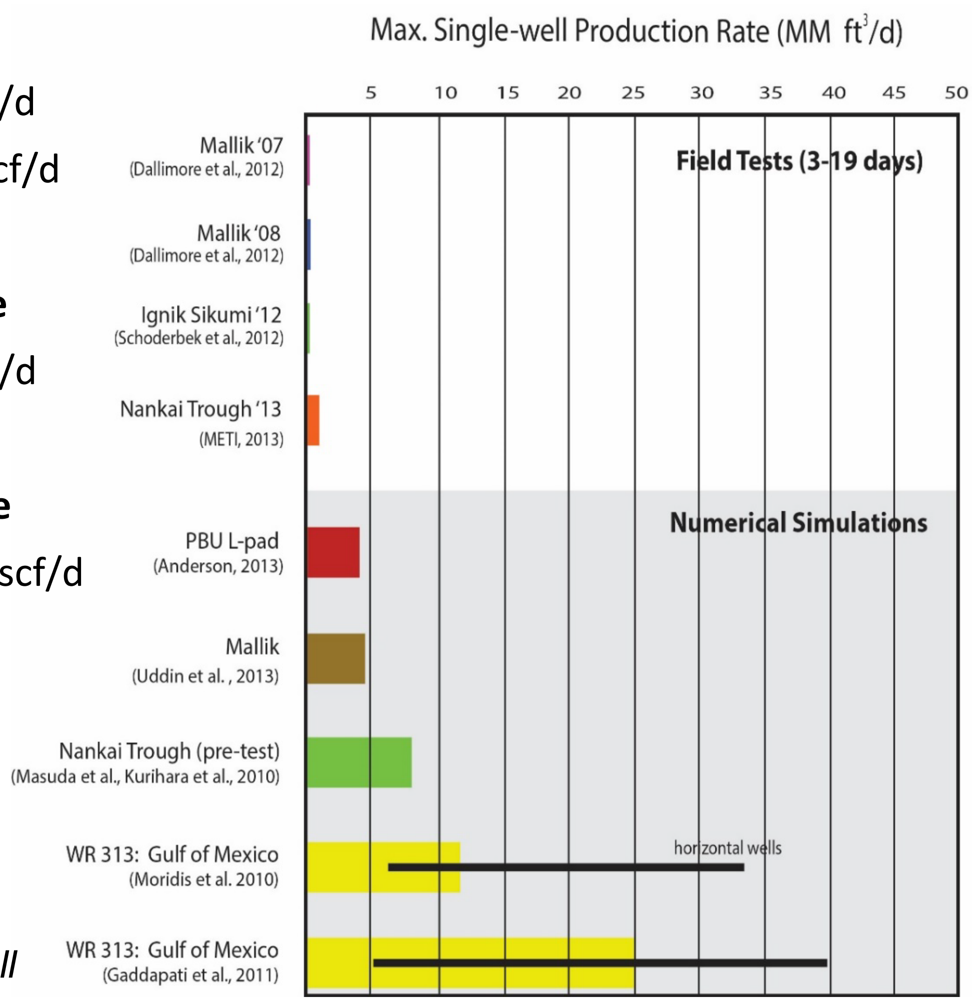
Economics

In most cases, unknown resource volume and unproven production technology

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

Simulation - Onshore
- Onshore: 4 mmscf/d

Simulation - Offshore
- Offshore: 40 mmscf/d



Modified from Boswell

GH Reserves

GH Resources

GH Reserves

Motivations

Production Technology

GH Resources
Where, How, Why

Gas Hydrates from Resources to Reserves

Economics

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

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 ^oC	700	5,000-8,000
-Alaska NS 10-12 ^oC	5,000	5,000-8,000
Gas Hydrate Modeling		
-Offshore	5,000-15,000	>20,000

Need to reduce development cost or increase production rate.

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

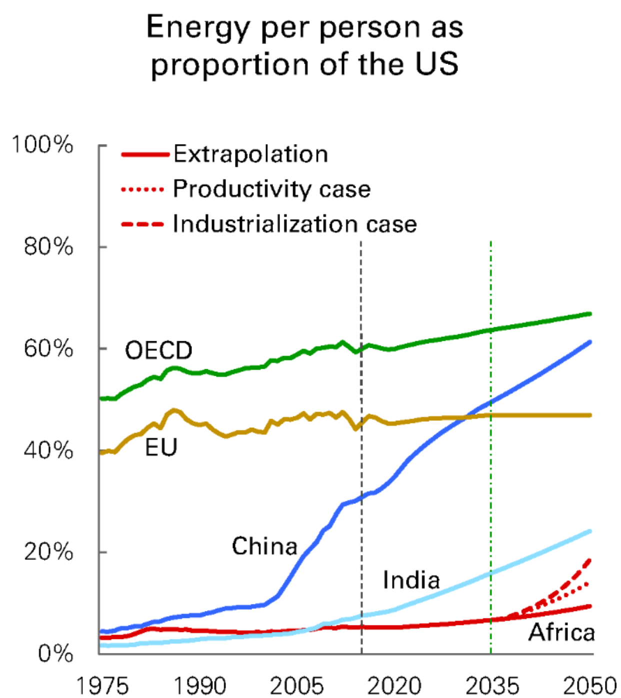
Impact taxation & climate change policies (royalties, Carbon-tax)

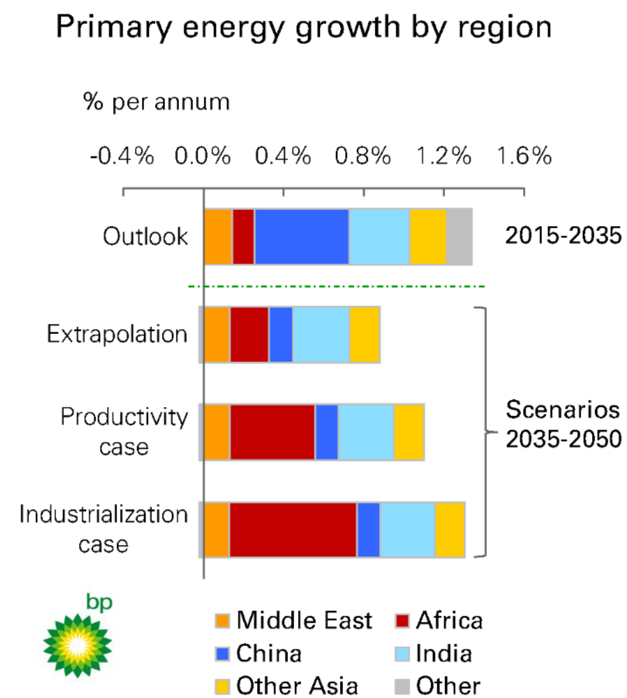
Establishment of government and industry partnerships

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 Resources

GH Reserves

Motivations

Production Technology

GH Resources
Where, How, Why

Summary of Challenges

- **In support of gas hydrate production modeling and testing efforts, continue to develop pressure coring equipment and pressure core analysis capabilities.**
- **"Scientific" 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.**
- **"Demonstration" 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.

Japan

Summary of R&D: Alaska and Nankai: 1995-2016

1998: First Mallik Well

1999: Nankai Discovery Well

2002: Mallik Thermal Production Test

2004: Nankai Exploration Program

2007: Mallik Depressurization Test #1

2008: Mallik Depressurization Test #2

2008: Nankai Trough Resource Assessment

2008: Exploration Approach Published

2012: Collaboration on Ignik Sikumi Program

2012: Preparatory drilling for Nankai Test

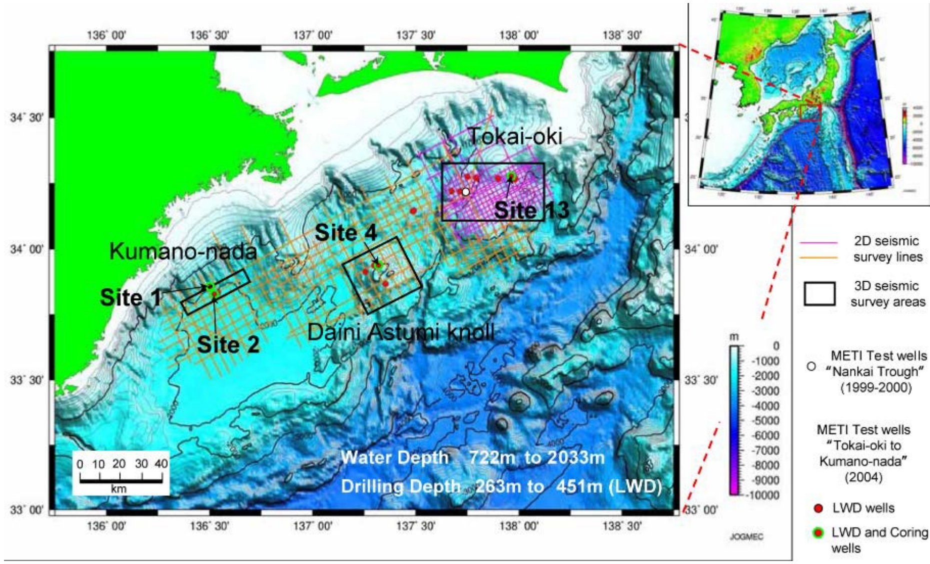
2013: First Nankai Production Test

2014-2018: Production Test Evaluation in Alaska

2016: Preparatory drilling for second Nankai Test

2017: Second Nankai Production Test

2018: Nankai Test Site Characterization



Japan

2013 and 2017 Production Tests in Nankai Trough

2013 Field Experiment

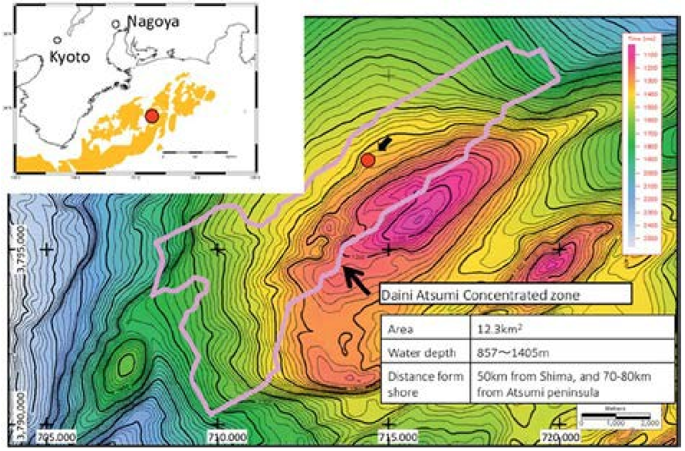
- Demonstration of technical recoverability
- 2 weeks planned: 1 week achieved
- Stable production obtained, but sand production issue

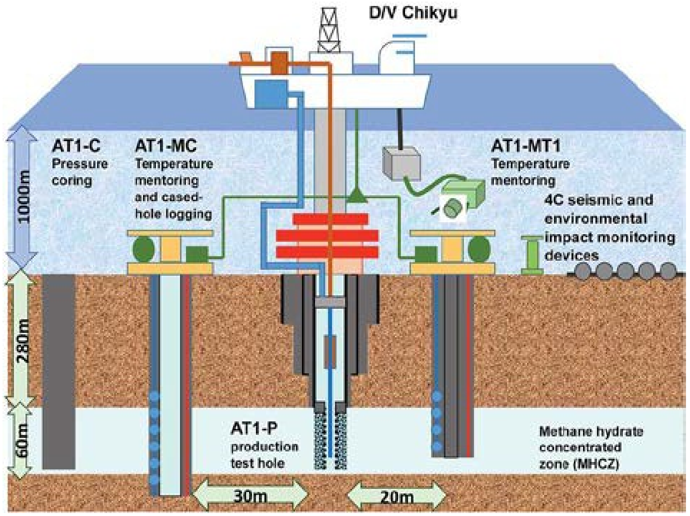
2017 Test

- Goal #1: Solve sand production issue
- Goal #2: Demonstrate increased rates over longer flow periods

Outcome: per METI: "As a result of this test, while one of the two production wells suffered the sand-intrusion problem, ANRE achieved a certain level of success from the second well, in which no problems occurred. However, ANRE could not clearly confirm an increase in the production rates at either of the wells, leaving challenges in establishing gas production technologies unsolved."

- Well #1: Approximately 35,000 m^3 in total in 12 days
- Well #2: Approximately 200,000 m^3 in total in 24 days





Fujii et al., 2015. Konno et al., 2017

India

DOE-MoPNG MoU: DOE-USGS-ONGC

India-US Collaboration

- Planning, execution of NGHP-01 and NGHP-02
- Evaluation and publication of Scientific Results from NGHP-01 (USGS, NETL, LBNL, GT, Scripps, OSU)
- Geophysical site review for NGHP-02 exploratory drilling
- Evaluation of NGHP-02 pressure cores (USGS, AIST)
- Geomechanical production simulations for potential NGHP-03 sites (NETL, LBNL, USGS)
- Evaluation and publication of Scientific Results from NGHP-02 (USGS, NETL, LBNL)
- Operational planning for NGHP-03


Contents lists available at ScienceDirect

Marine and Petroleum Geology

journal homepage: www.elsevier.com/locate/marpetgeo

ELSEVIER

Research paper

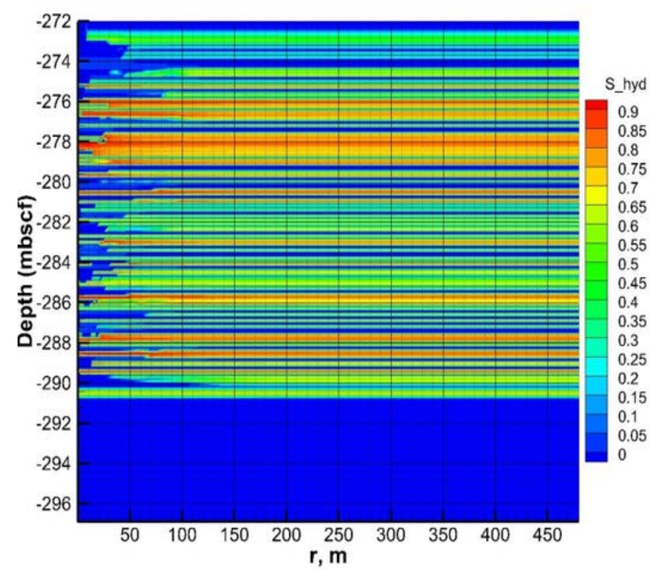
Geologic implications of gas hydrates in the offshore of India: Results of the National Gas Hydrate Program Expedition 01

Timothy S. Collett [a,*], Ray Boswell [b], James R. Cochran [c], Pushpendra Kumar [d], Malcolm Lall [e], Aninda Mazumdar [f], Mangipudi Venkata Ramana [g], Tammisetti Ramprasad [f], Michael Riedel [h], Kalachand Sain [i], Arun Vasant Sathe [j], Krishna Vishwanath [e], NGHP Expedition 01 Scientific Party

Science Results for NGHP-01

NGHP-02 p-cores arrive at USGS labs in Woods Hole

NETL modeling for potential NGHP-03 Site 16

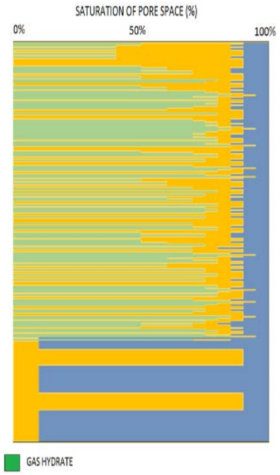


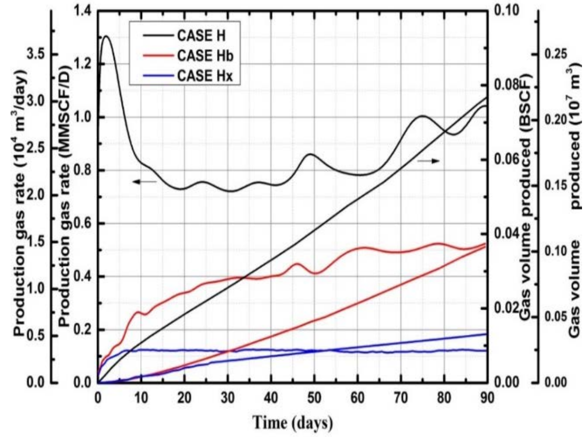
India

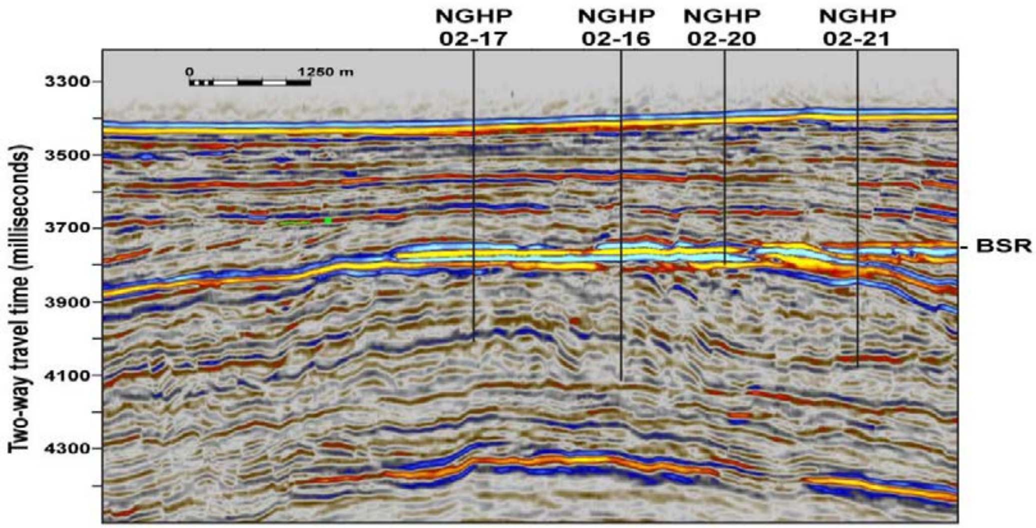
Detailed geologic input model (NETL/USGS)

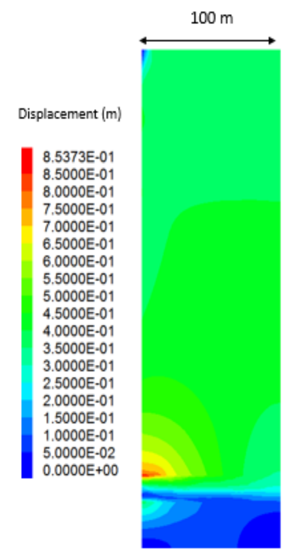
State-of-the-art flow and geomechanical modeling for primary site (Site 16 – Area B)

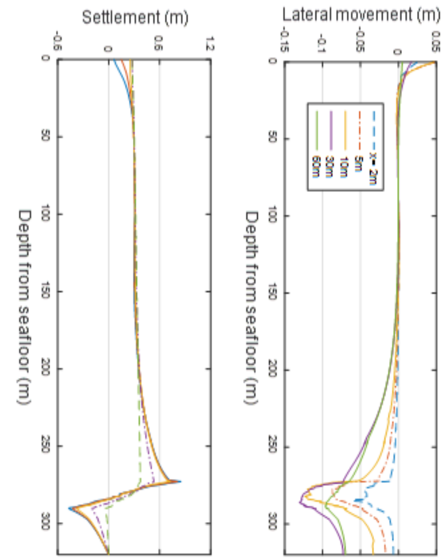
- “Site 16” NETL/USGS (w/ AECOM; Pitt; RPI)
- “Site 9”: NETL/USGS (w/ LBNL)



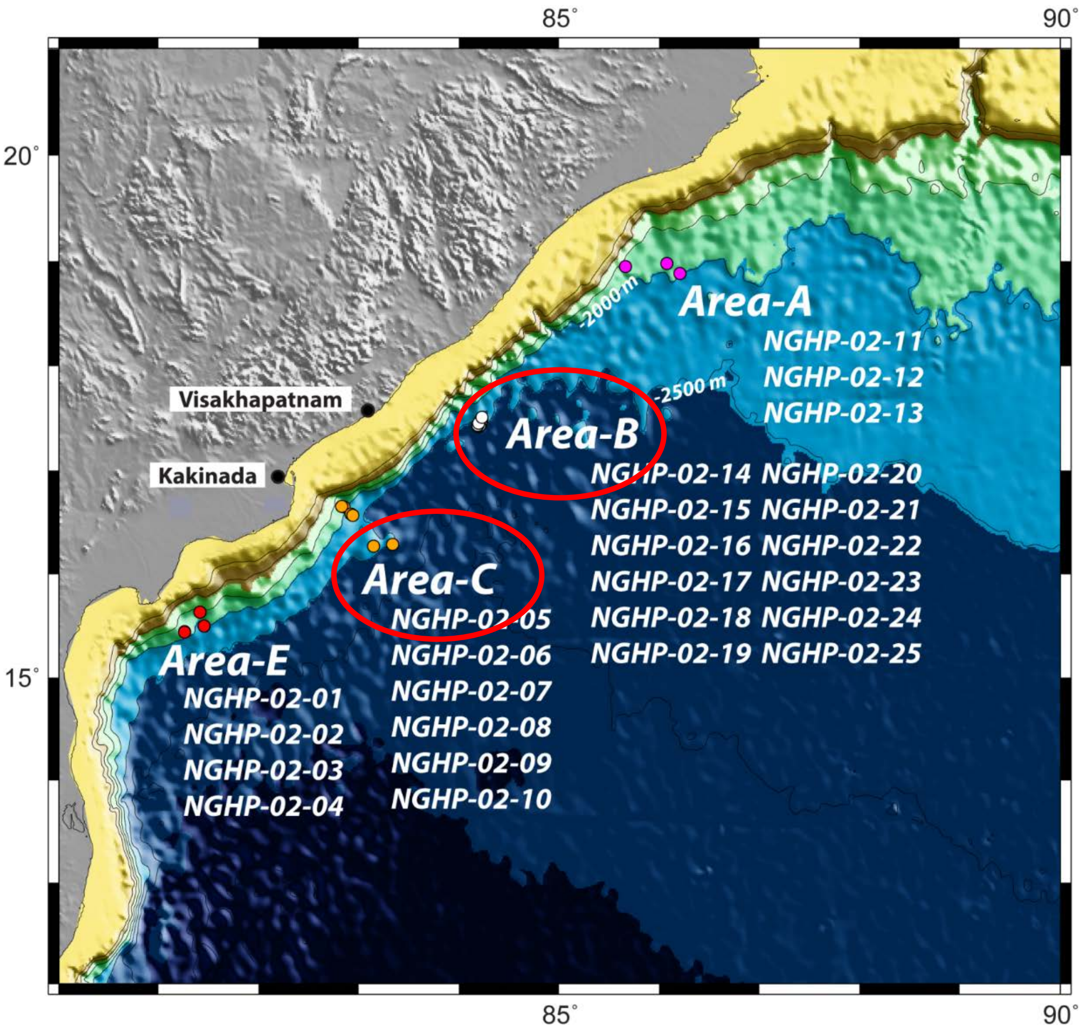








India NGHP-02 (2015)



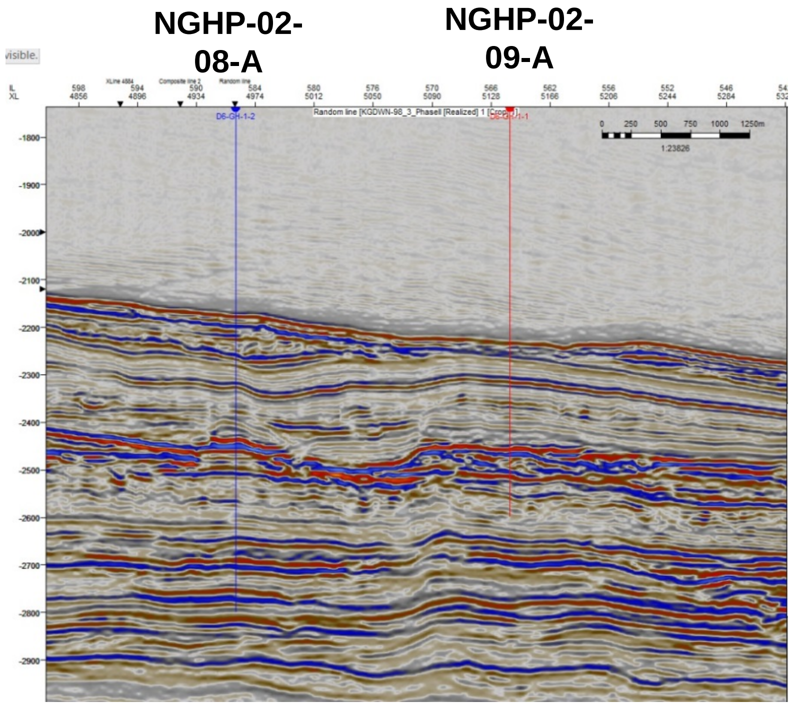
- Advance pre-drill prospect review
- Total of 42 holes were completed in 147 days. Water depths 1,519-2,815 m
- Total of 25 LWD holes, conventional and pressure (106) cores were acquired in 16 wells, wireline logging and MDT testing
- Concentrated GH reservoir systems in both Area-B and Area-C matching 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

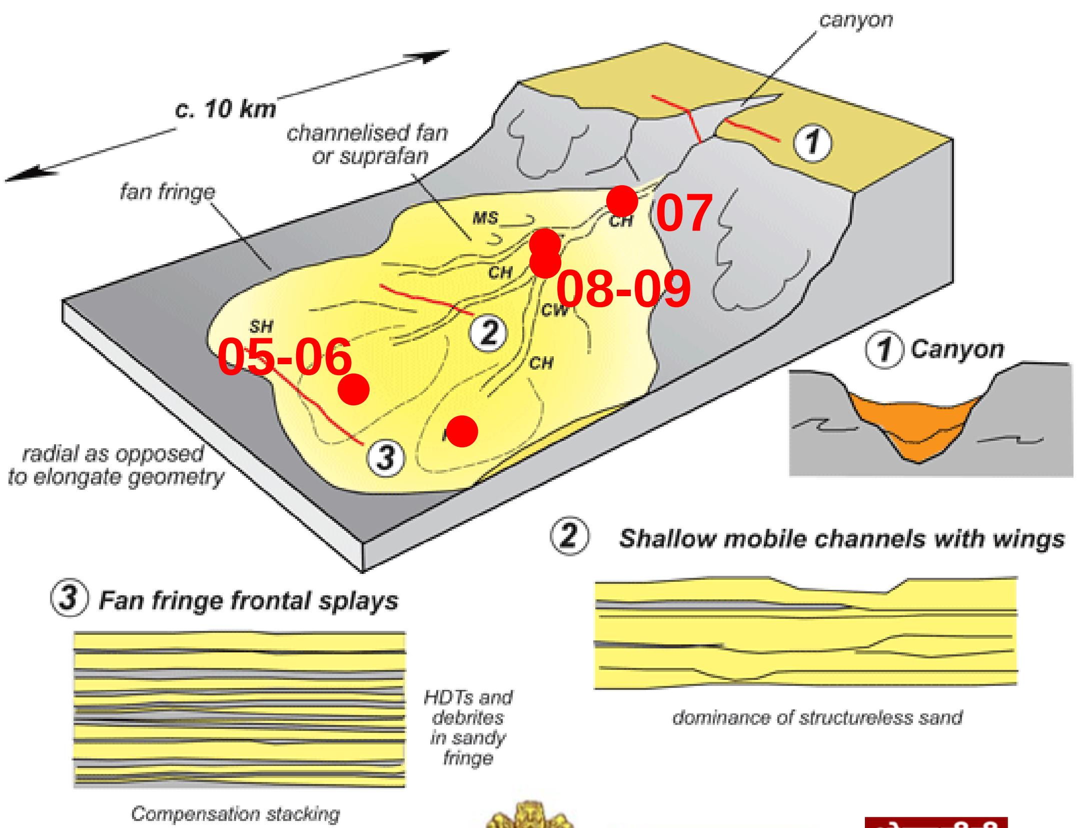
सत्यमेव जयते

DGH

ओएनजीसी ONGC

India NGHP-02 (2015): Area-C



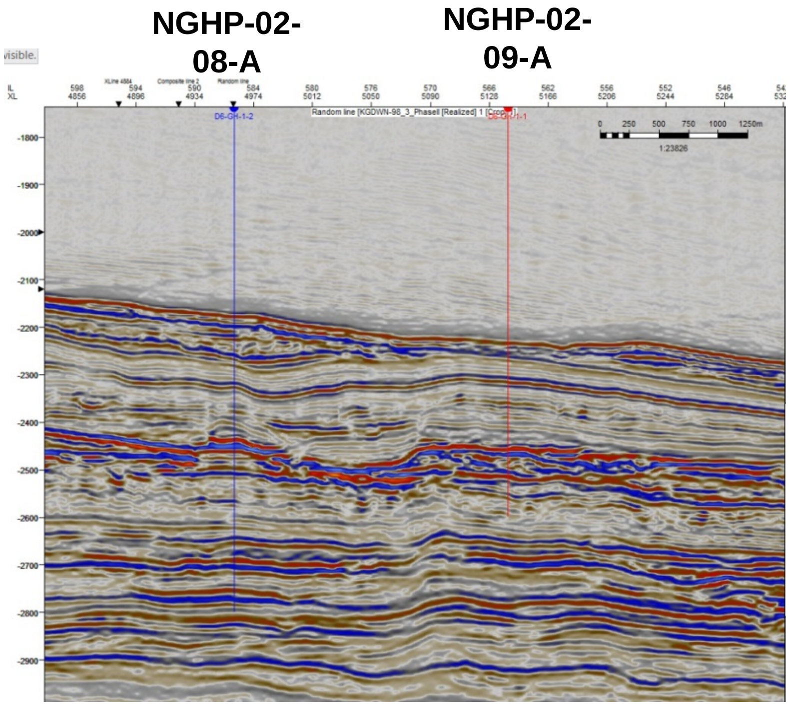


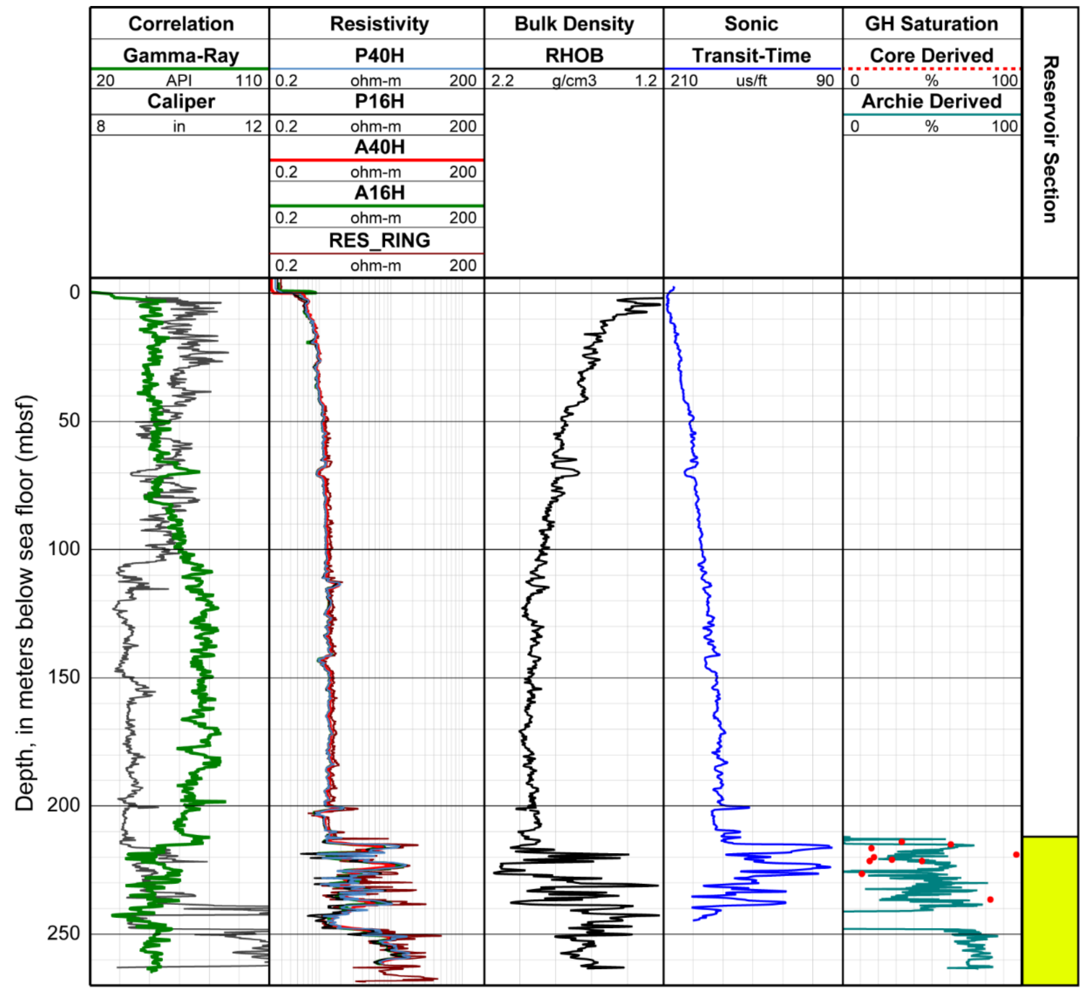
Core NGHP-02-09B-35P

Area C: Krishna-Godavari Gas Hydrate Petroleum System

Slope-Rise Channel-Levee System

India NGHP-02 (2015): Area-C



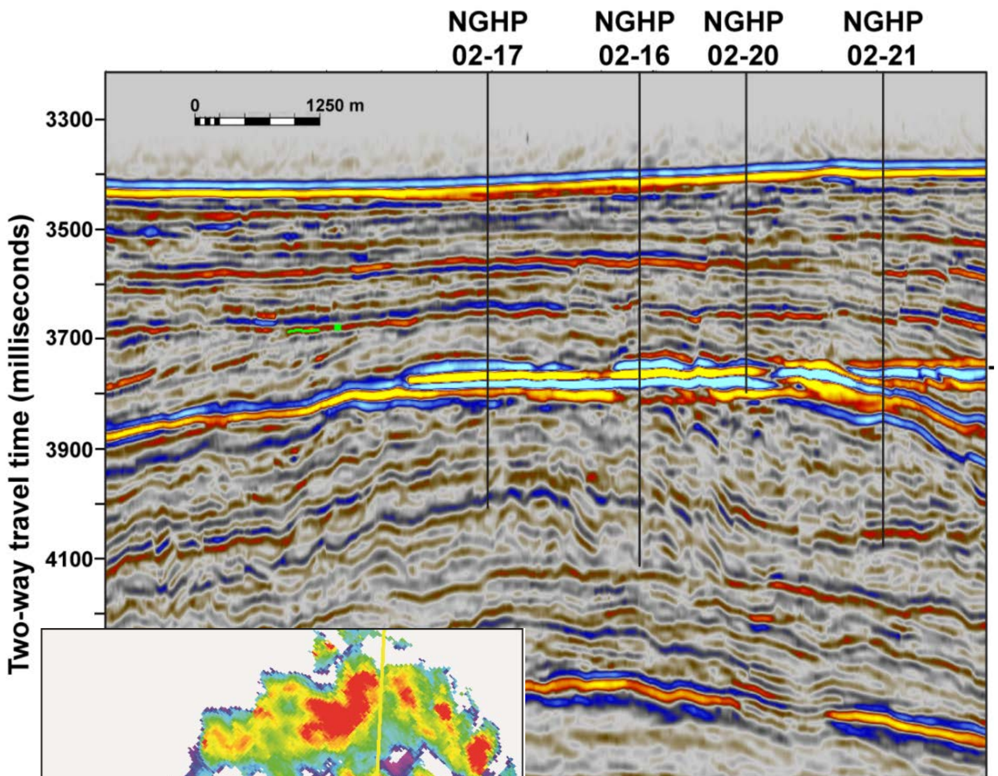


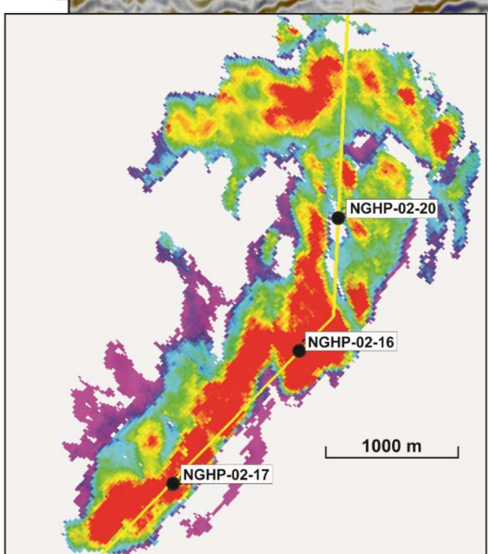
Core NGHP-02-09B-35P

Area C: Krishna-Godavari Gas Hydrate Petroleum System

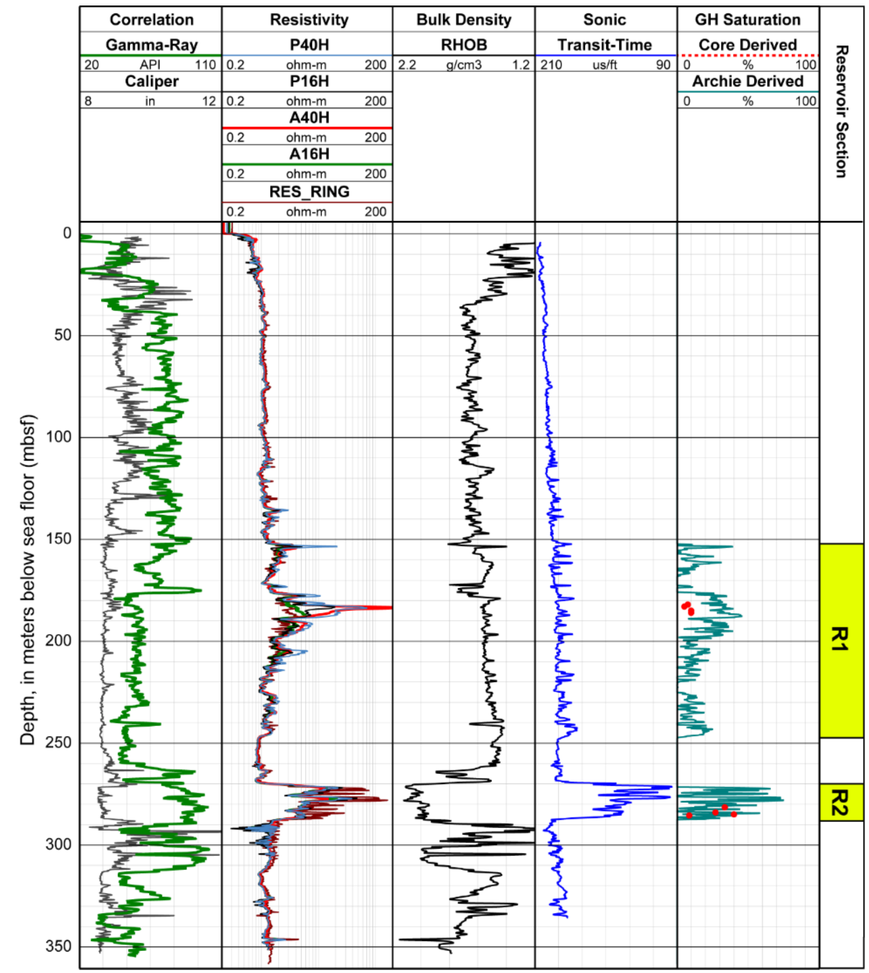
Slope-Rise Channel-Levee System

India NGHP-02: Area-B

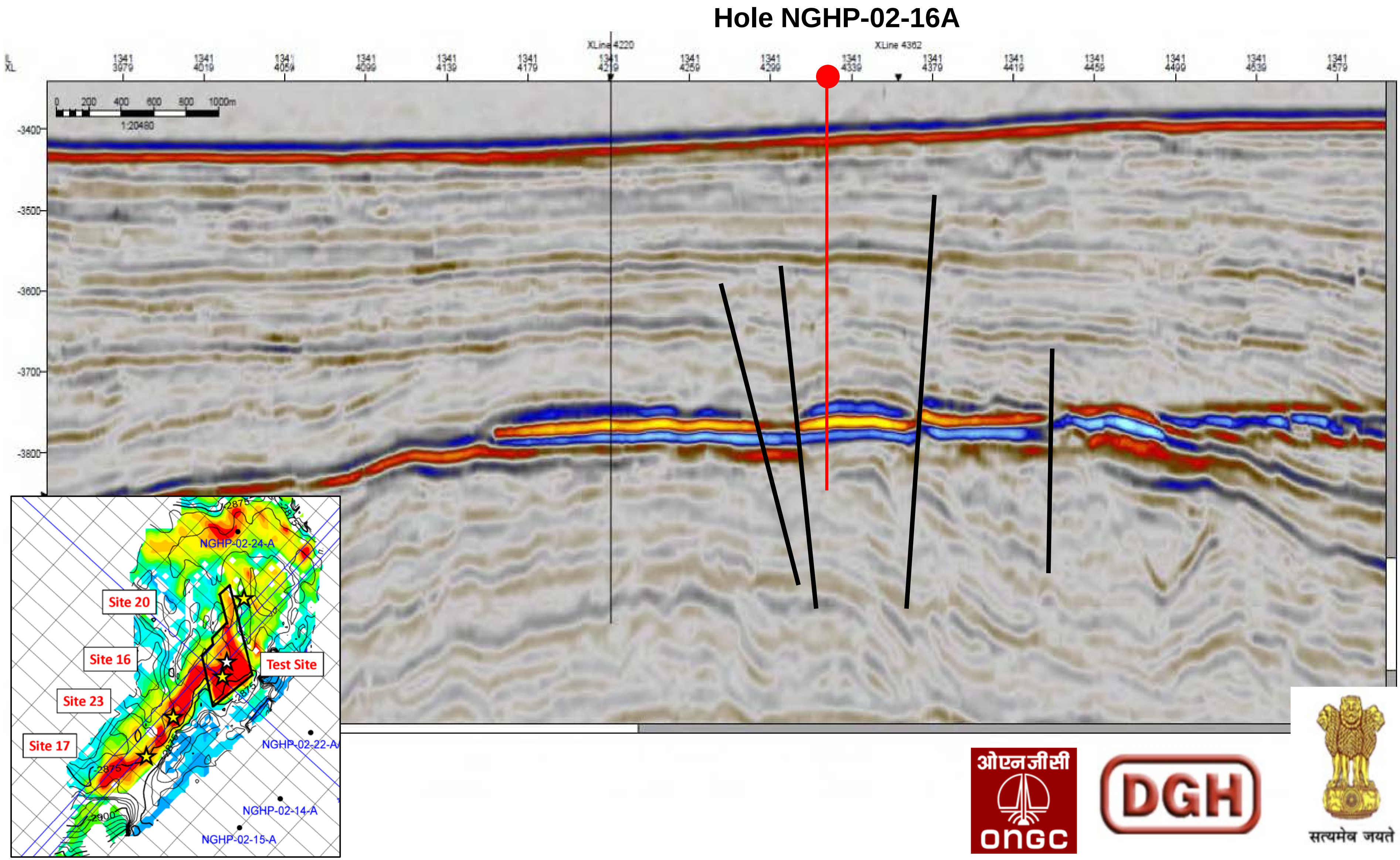




NGHP-02-16



NGHP-02 Area-B Lower (R2) Reservoir



S. Korea

DOE-MKE MoU: NETL-TAMU-KIGAM CA: NETL-GHDO joint funding for NL FWPs

UBGH-01 (2007)/UBGH-02 (2010)

- Substantial USGS support
- DOE support for US scientist participation
- Special Volume publication in 2014

NETL, USGS, LBNL support for UBGH-03 planning

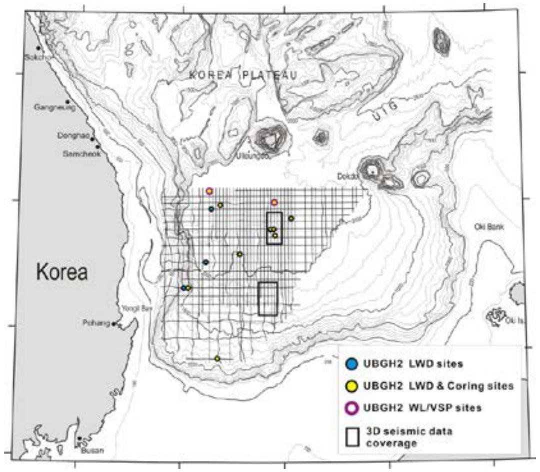
- Site selection advisory committee
- Numerical prediction of production response

Numerical Simulation Studies

- Ongoing Collaborations KIGAM, LBNL, PNL

Collaboration with Texas A&M

- Project leverages data KIGAMs unique large-scale reactors



S. Korea

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- DOE support for US scientist participation
- Special Volume publication in 2014

NETL, USGS, LBNL support for UBGH-03 planning

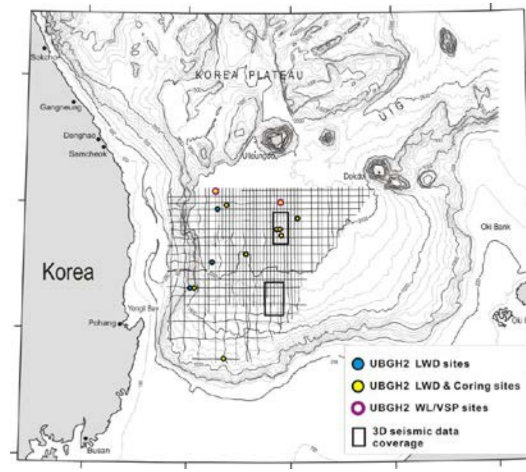
- Site selection
- Numerical prediction of reservoir response

Joint Funding for Numerical Simulation Studies

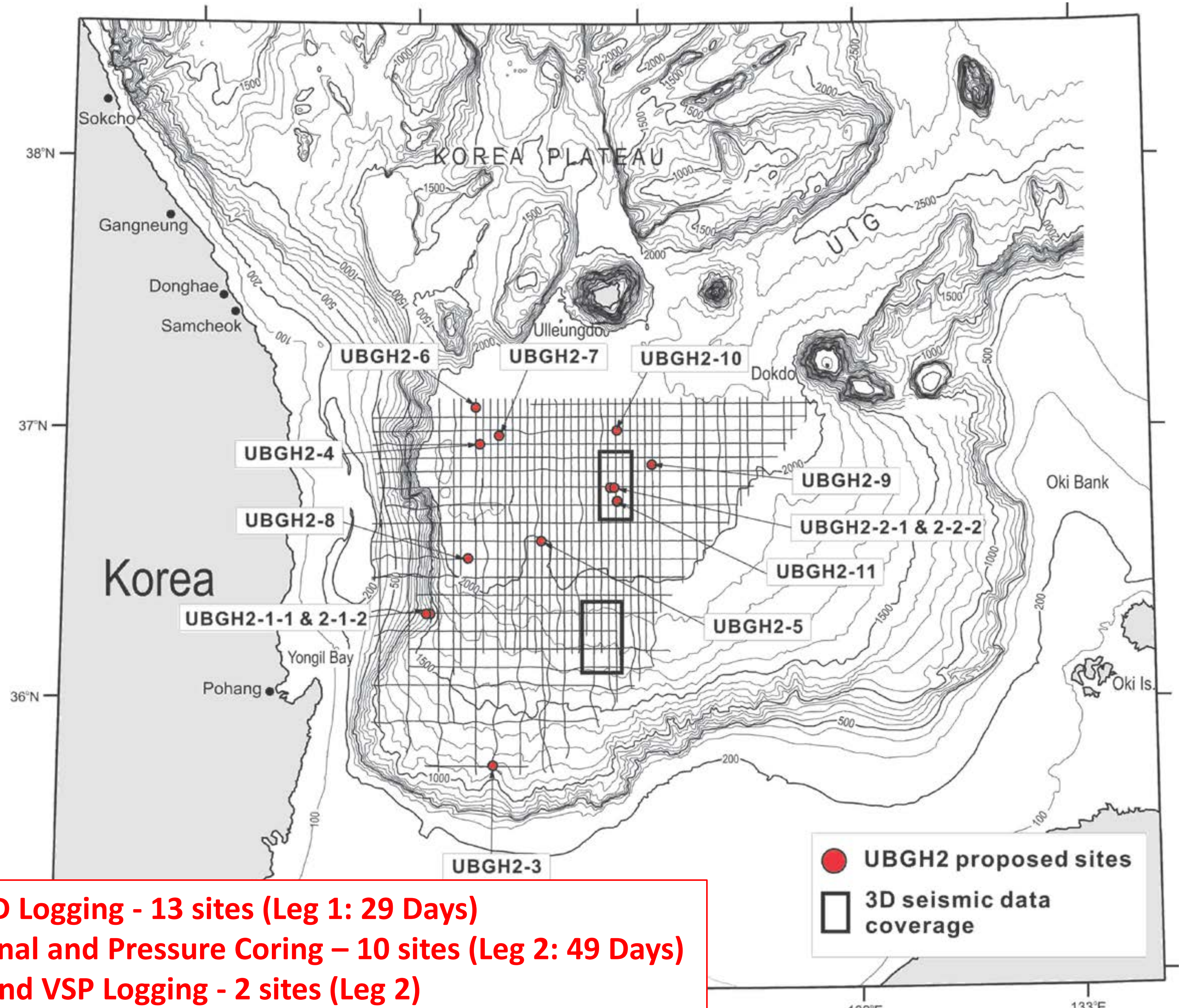
- Denver Meeting in 2014 □projects with LBNL and PNL
- Geoscience and assessment projects with the USGS

New Cooperative Agreement with Texas A&M

- Ex KIGAM/LBNL modeler JiHoon Kim now at TAMU
- KIGAMs unique large-scale reactors

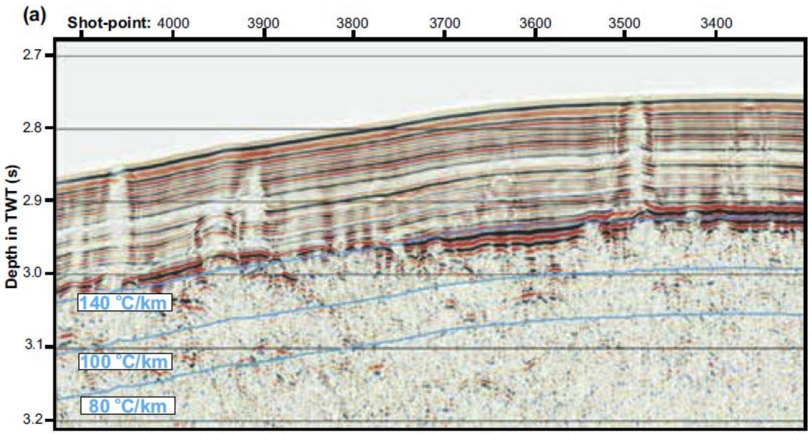


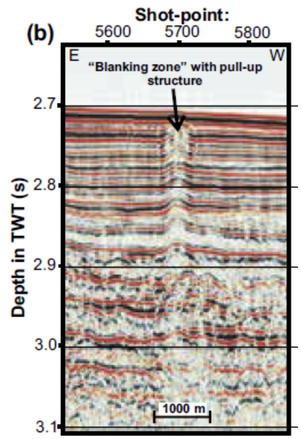
Ulleung Basin Gas Hydrate Drilling Expedition (UBGH2) 2010



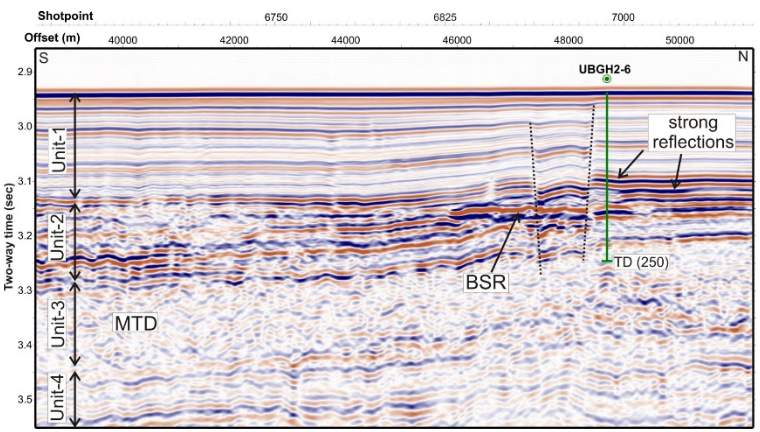
LWD-MWD Logging - 13 sites (Leg 1: 29 Days)
Conventional and Pressure Coring – 10 sites (Leg 2: 49 Days)
Wireline and VSP Logging - 2 sites (Leg 2)

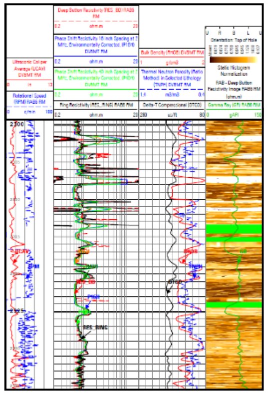
Ulleung Basin Gas Hydrate Prospects



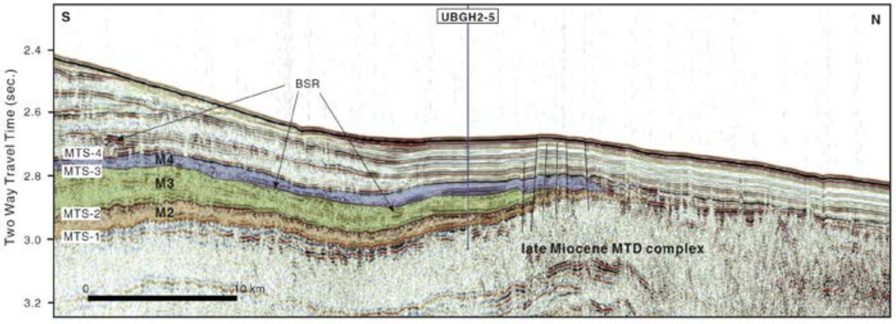


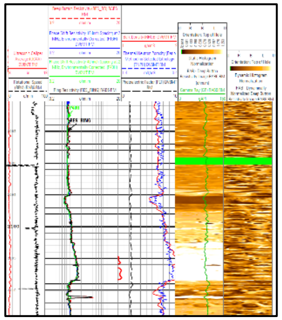
Chimney structures





Turbidite sands





Sandy debris flows

LWD-MWD Logging - 13 sites (Leg 1)
Conventional and Pressure Coring – 10 sites (Leg 2)
Wireline and VSP Logging - 2 sites (Leg 2)

KIGAM Korea Institute of Geoscience and Mineral Resources

교육기부기관
교육부

INTERNATIONAL SCHOOL FOR GEOSCIENCE RESOURCES (IS-Geo)
KOREA INSTITUTE OF GEOSCIENCE AND MINERAL RESOURCES (KIGAM)

Uconventional Oil and Gas Resources Regular Training Course

Module 3. Gas Hydrate (February 5-9, 2018)

Day 1. Gas Hydrate Structures, Stability, and Physical Properties by Drs. Lee, Collett, Waite
Day 2. Gas Hydrate Systems and Geophysical Characterization by Drs. Haines, Collett, Ryu
Day 3. Gas Hydrate Production Field, Laboratory, and Modeling Studies by Drs. Seol, Waite
Day 4. Gas Hydrate System Response to Production by Dr. J-Y Lee
Day 5. Gas Hydrate Geohazard, Climate, and Production Research and Challenges by Dr. Collett, Waite, Ryu
Day 6. Vist *R/V Tamhae II*

Participants from Korea, Cambodia, Indonesia, Laos, Malaysia, Myanmar, Peru, Phillipines, Thailand, Vietnam
Instructors Collett, Waite, Haines (USGS); Seol (DOE-NETL); Ryu, Lee (KIGAM)

China

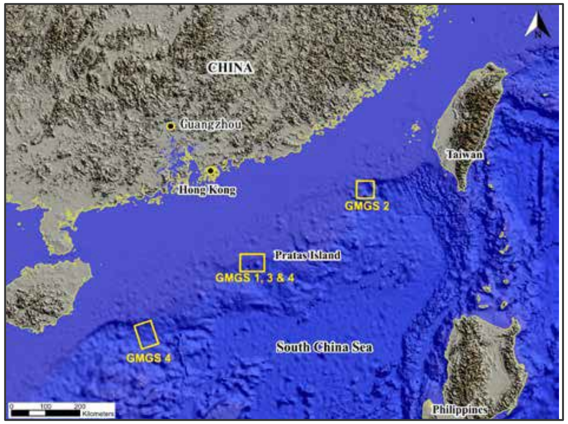
Very Active Program

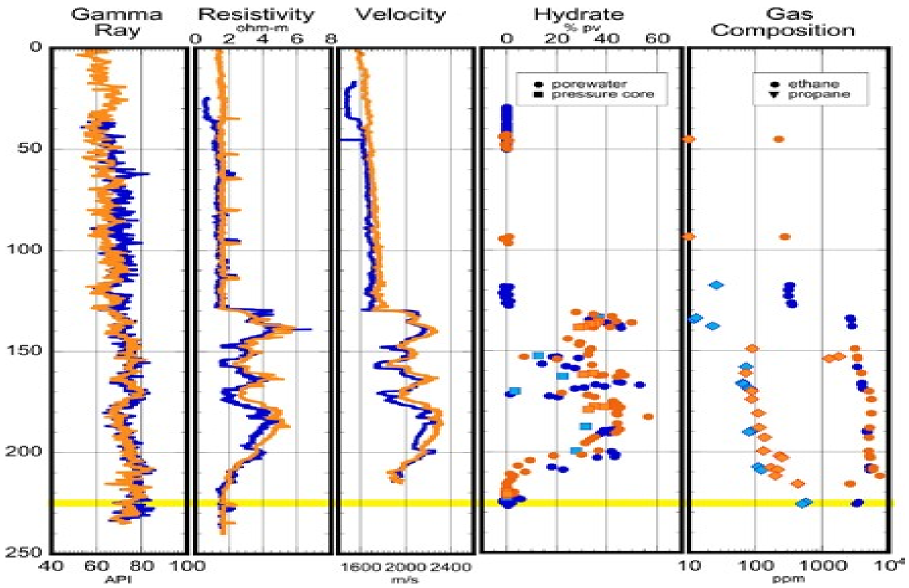
GMGS-2 (2013), GMGS-3 (2015) and GMGS-4 (2016)

- NETL publishes first public reports in FITI newsletter
- Primary focus is Pearl River mouth basin (Shenhu area)
- GMGS-4 added new area to the south (Xisha area); 58 days/ 21 sites
- Reservoirs appear to be clay-rich silt with $S_{gh.}$ up to 40% (anomalous)
- Lateral heterogeneity over short distances.
- 20-90 m thick at BGHS: Some Structure II GH?

Onshore Testing Underway

- Permafrost-associated: Thermogenic; Fractured-rock reservoirs
- Tibetan Plateau (Qilian) and Manchuria (Mohe))





Yang et al., FITI, 2017

China

2017 Production Test

Bluewhale 1 & 2
CPOE Operator
CNPC Client
First deployment – SCS GH testing

Test site in South China Sea
Test zone ~250 mbsf
WD = 1,266 m

Ministry of Land and Resources
60 days → 309,000 m^3

China Geological Survey
80 billion metric tons of reserves

China has invited other South China Sea countries to join in collaborative field production testing at the site
Under the leadership of CNPC

New gas hydrate center ancounced for CNOOC in Beijing

China

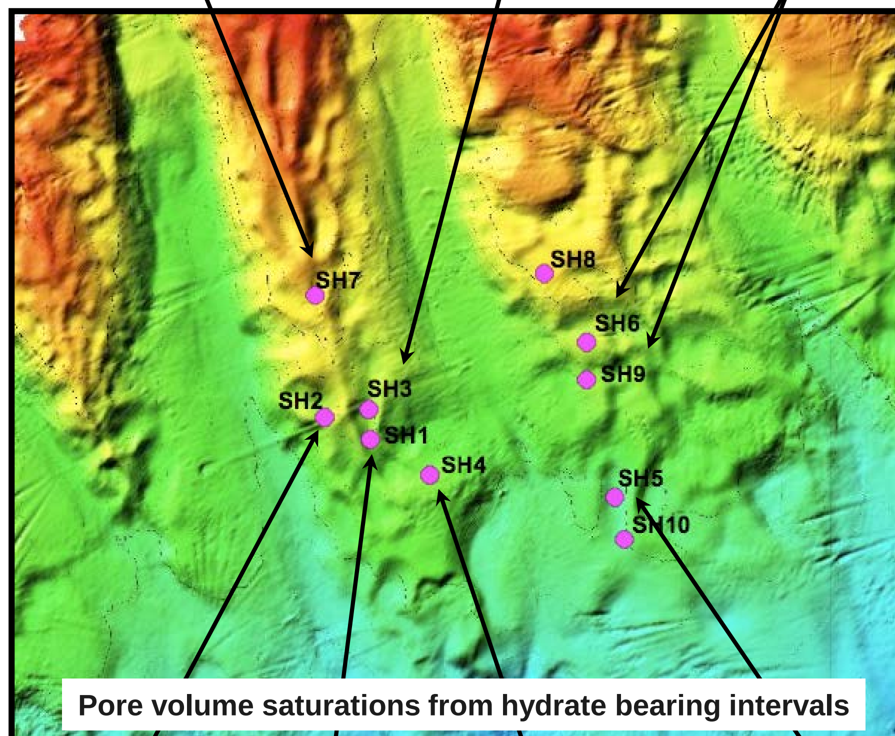
2017 Production Test

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

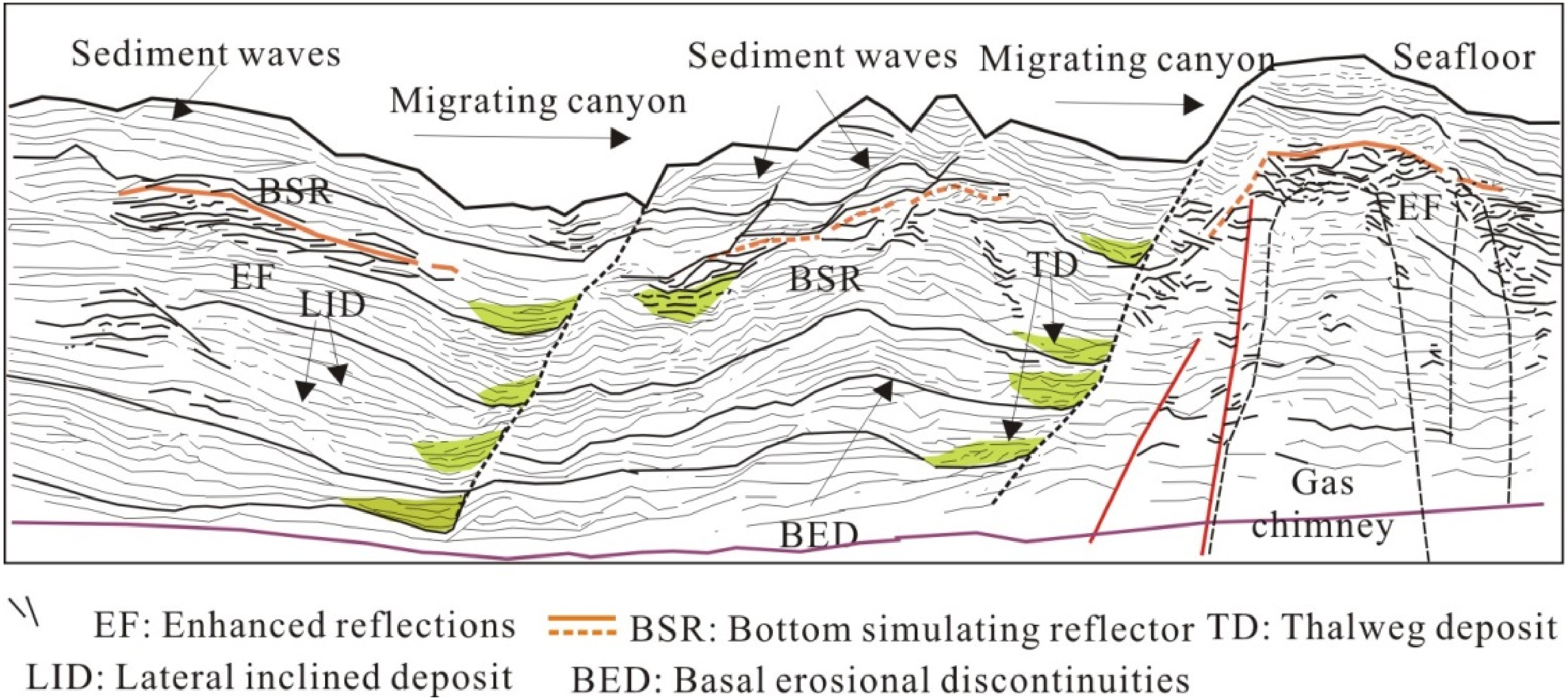
China successfully extracted natural gas hydrate for the first time in the Shenhu area of the South China Sea on Thursday, China Geological Survey announced. China Geological Survey (CGS), under the Ministry of Land and Resources, was in charge of the natural gas hydrate extraction test project, which 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).

GMGS-1 Results

- 8 sites were drilled, 5 sites were extensively sampled
- Water depths of up to 1500 m
- Coring & drilling up to 250 mbsf
- Presence of hydrate confirmed at three locations (plus one sand-rich reservoir)
  - Layer above GHSZ, 10 to 25+ m thick
  - Disseminated in fine grained, foram-bearing to rich clay interval
  - Saturations of 20 to 40% of the pore volume
  - Gas composition was 99% methane
- Post-cruise analyses
  - Interpretation/review of datasets collected at sea
  - Analysis of samples, such as frozen gas hydrate-bearing sediment, pressure cores, etc.



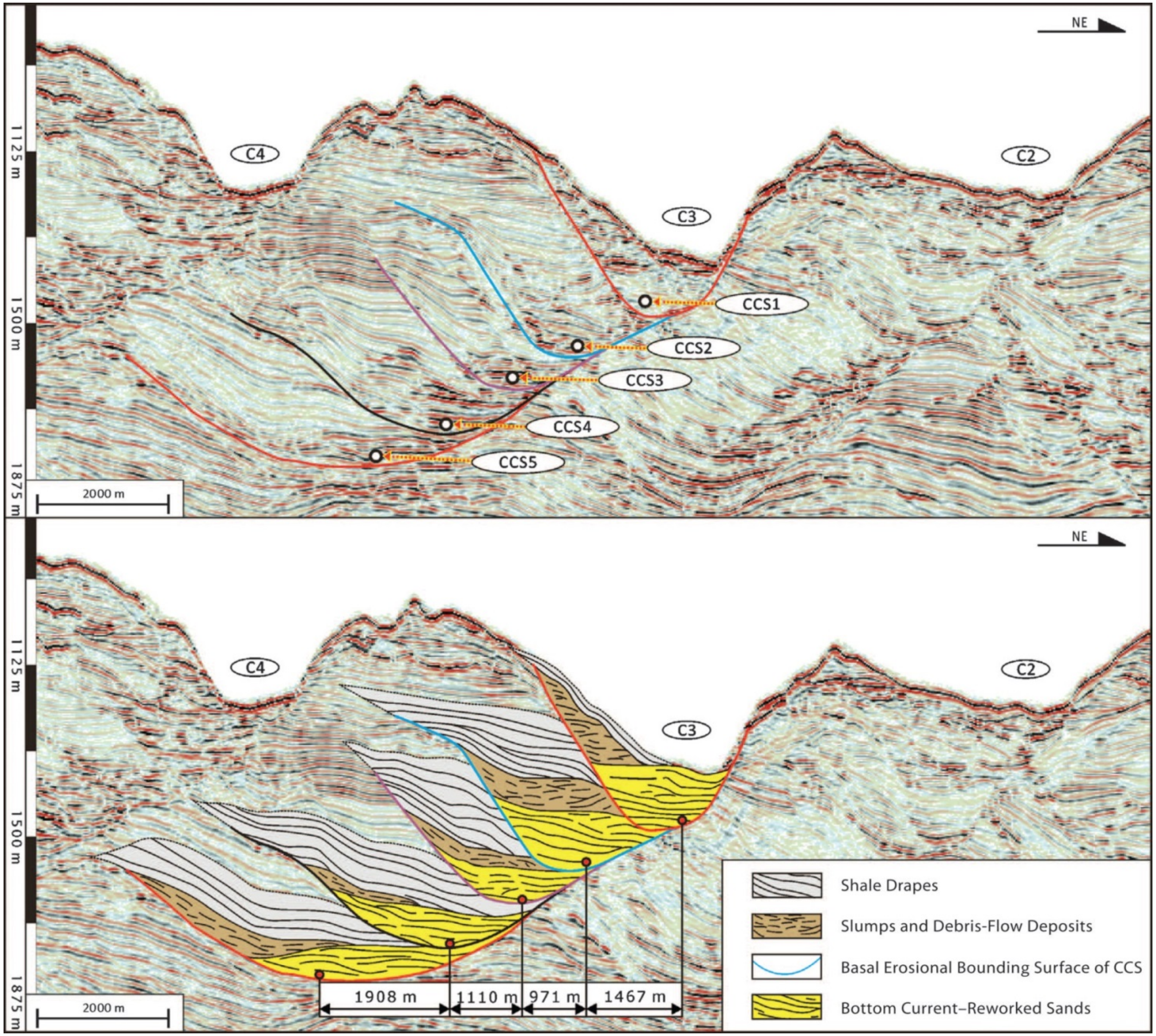
Shenhu Area Depositional System



Xiujuan Wang et al., 2014

Baiyun Depression
Pearl River Mouth Basin

Facies and architecture within unidirectionally migrating deepwater channel



Chenglin Gong et al., 2014

Baiyun Depression
Pearl River Mouth Basin

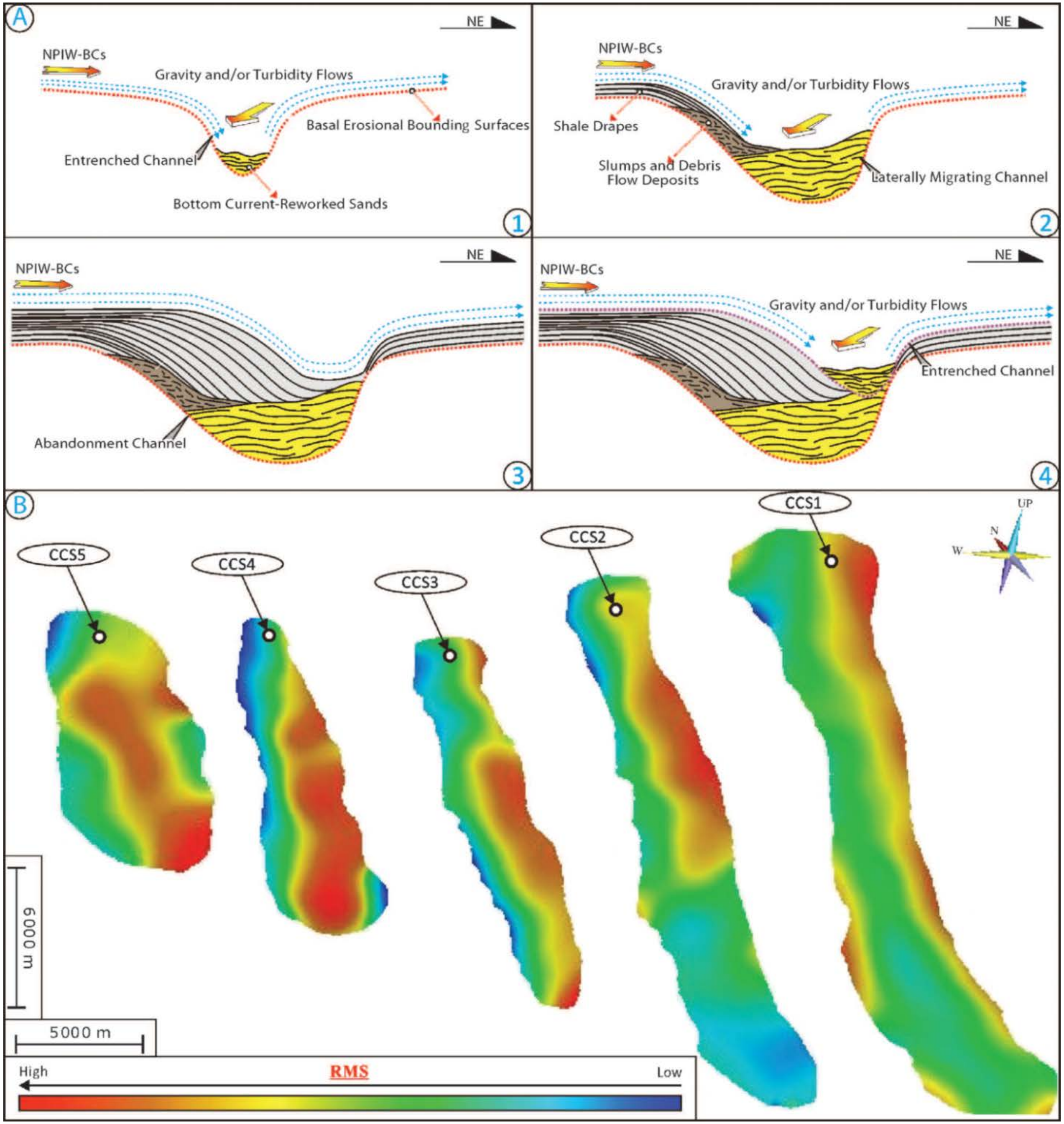
Migrating channel-complex

-Lowstand incision stage

-Lowstand lateral migration and active fill stage

-Transgression abandonment stage with clay drape

Sands accumulate along the axis of the migrating channels



Chenglin Gong et al., 2014

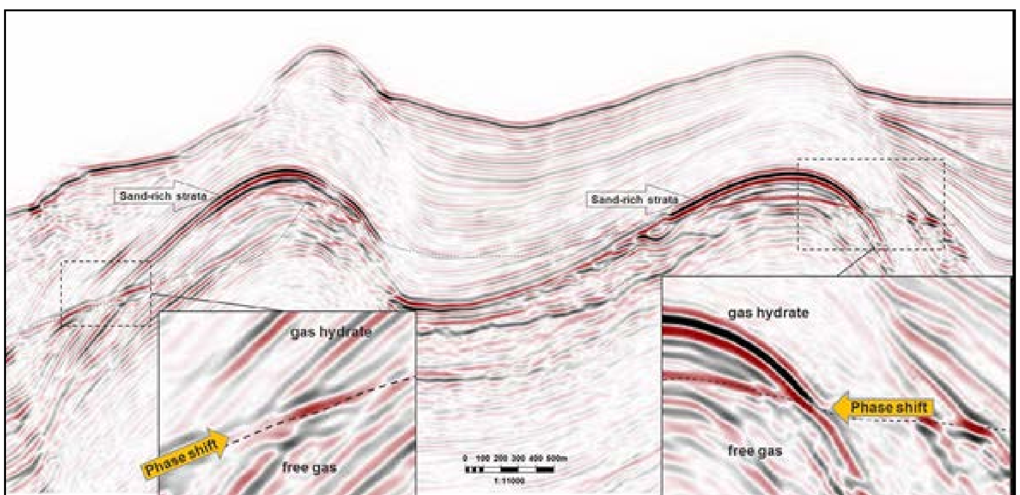
A Global Review of Gas Hydrate Resource Potential

Thomas Reichel and Joseph W. Gallagher, Statoil ASA, Oslo, Norway

Method:
- Start with 567 basins
- GHSZ
- Hydrocarbon system
- Seismic characterization

Hydrocarbon system:
- Hydrocarbon source
- Migration into the GHSZ
- Reservoir (sand)
- Reservoir seal

Results:
- Favorable basins 256
- Total of 197 basins evaluated
- Good potential - 14 basins
- Resources - 5 tril cubic meters



Other International

Informal Collaborations

New Zealand

- IODP Exp.-372 (Nov '17 to Jan '18). "Creeping Deformation"
- NETL supported recent NRL/GNS studies
- NETL supports Stanford U. in NZ PetroMod studies

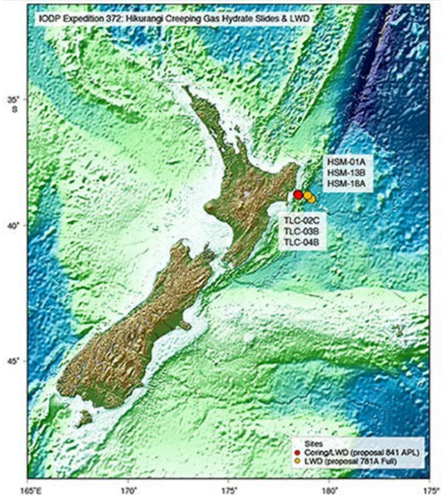
Europe

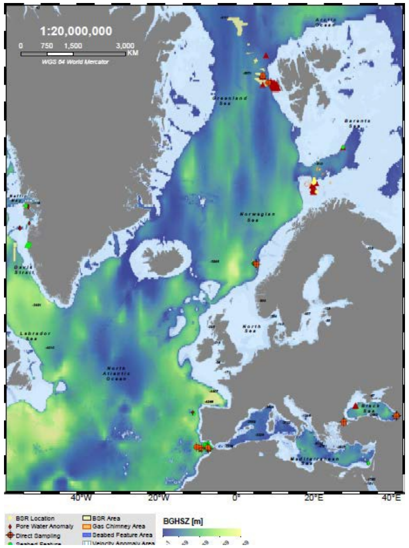
Resource evaluation

- CAGE & MARUM (U. Bremen) expeditions to Svalbard
- CAGE at University Tromso:
- "Sugar" Project at GEOMAR. Black Sea MeBO drilling
- Engagement with Statoil

Other

- Engagement with SENER, IMP (Mexico)
- Engagement with Petrobras
- Ireland, Uruguay, Colombia, S. Africa, Turkey, Vietnam, Taiwan
- Recent publications of ga shydrates offshore Columbia and Malaysia



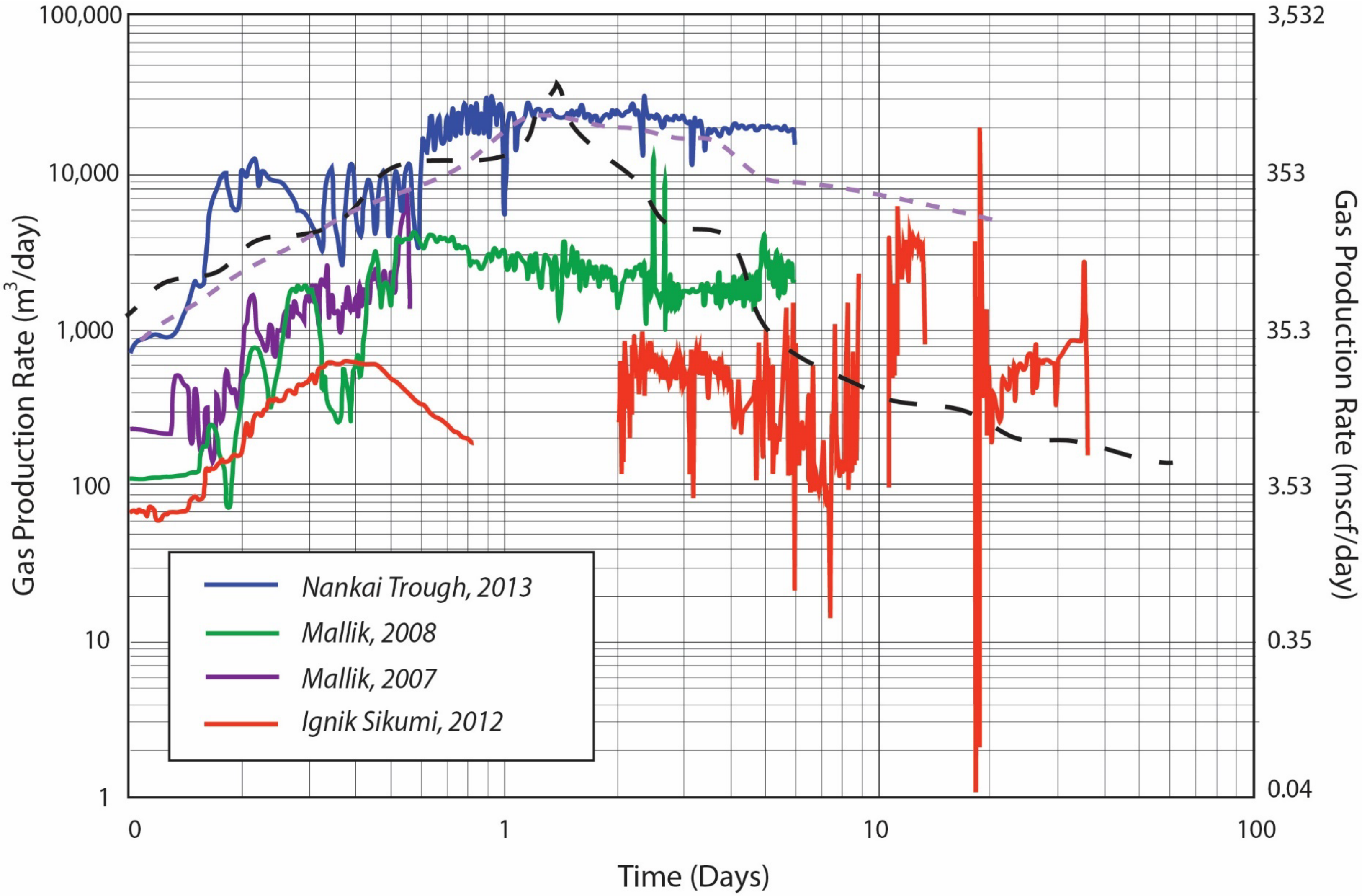


MIGRATE (Minshull et al.)

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)**
  - 1^{st} Marine GH production test (6-days)
- **2017 South China Sea Test (China)**
  - Marine GH production test (60-days*)*
- ***2017 Nankai Trough Test (Japan)***
  - Marine GH production test (two test 10-30 days)
- ***2018-2020 DOE-JOGMEC Alaska***
  - *Extended depressurization testing*
- ***2018-2019 KG Basin Offshore Test (India)***
  - *Extended depressurization test*

Recent Test Results – Speculative



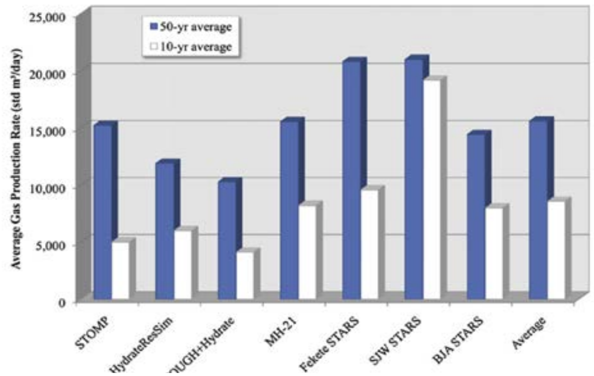
Int’l Gas Hydrate Code Comparison

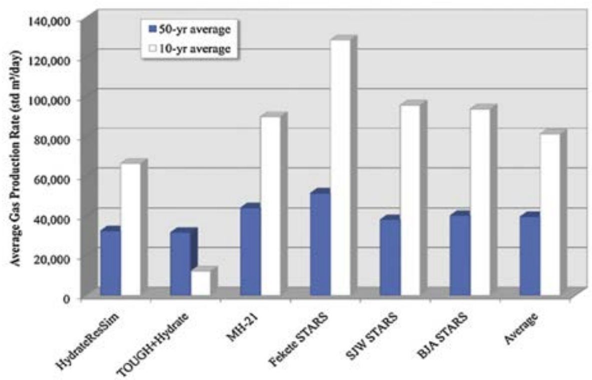
2005-2011: Thermodynamics and hydraulics (US, Japan, Canada)

- Wilder et al., 2008 (ICGH-6): Anderson et al., 2011 (J. Mar Pet Geol 28)

2017: Integration of geomechanics (US, Japan, Korea, China, Germany, UK)

2017: Collaborative Modeling with Japan and for key sites in India

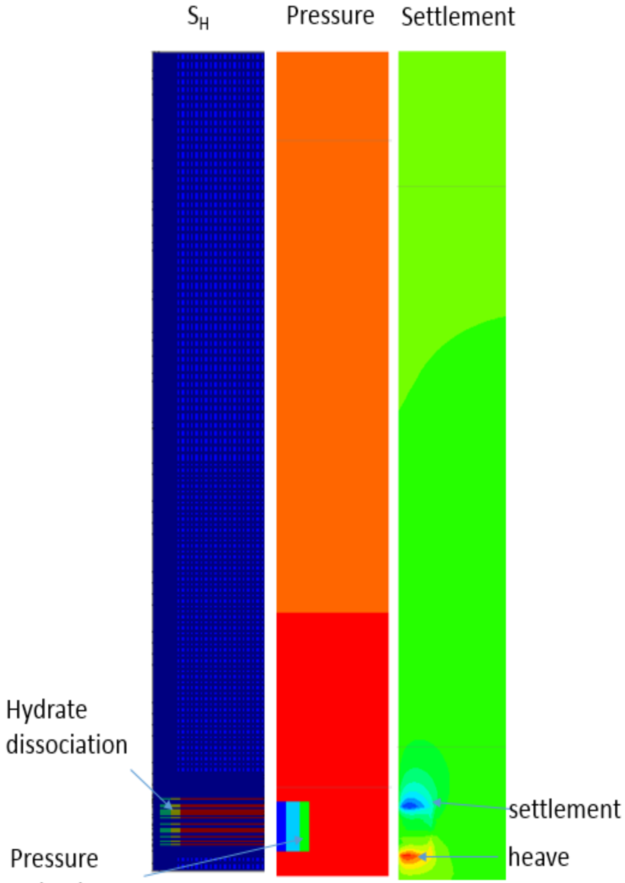




Geomechan. & Sand Production Modeling

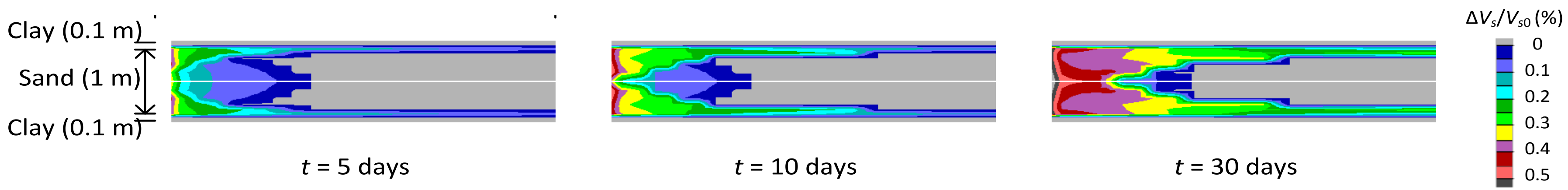
In Support of NGHP-03 Planning

- **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

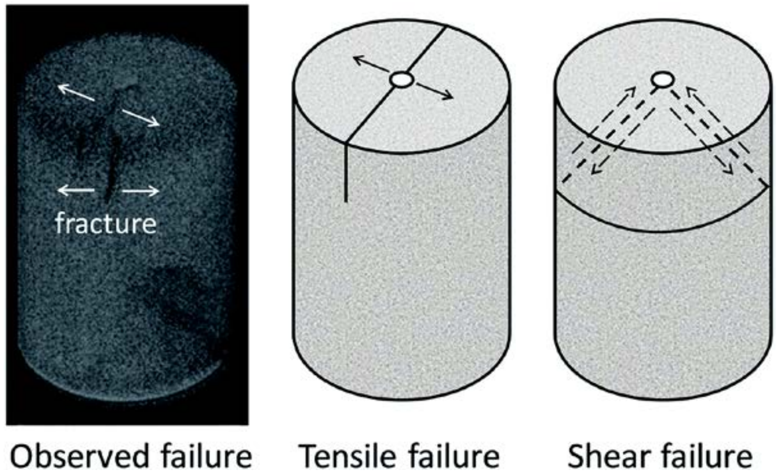


Gas Hydrate Production

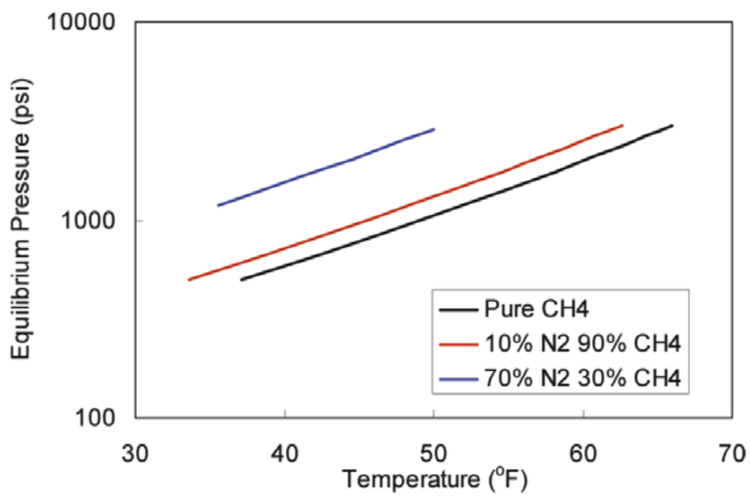
"Conventional" and Enhanced Methods

- **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



Production Technology Evaluation

NATIONAL ENERGY TECHNOLOGY LABORATORY

Well Completion, Production, Intervention

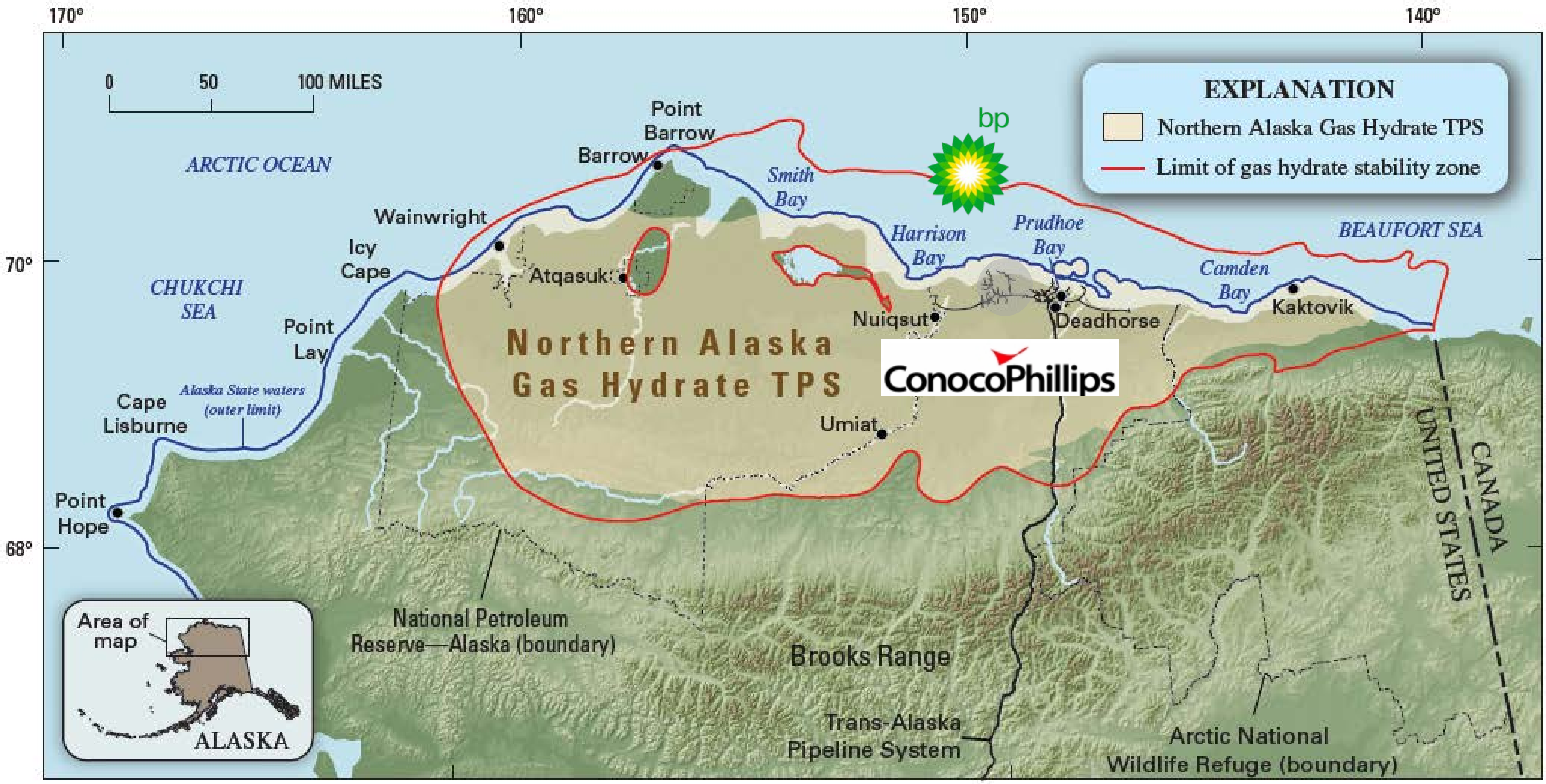
- Mud-chiller
- MOBM
- Sidewall pressure coring
- Whole core pressure coring
- Pressure core analyses (onsite and lab-based)
- Full suite LWD and wireline logs
- Monitoring inside and outside casing
- Fiber-optic Temperature Monitoring (DTS)
- Fiber-optic Strain Monitoring (DSS)
- Fiber-optic Acoustic Monitoring (DAS)
- Pressure/Temperature monitoring (gauges)
- Brillouin Scattering System – Strain Monitoring
- VSP (traditional vs. DAS)
- Artificial Lift (ESP, Jet-pumps, TBD)
- Sand control completion

Examples of tools under consideration

Integration of GH Reservoir Data

- Pressure (permeability) and Temperature Controls

Alaska North Slope

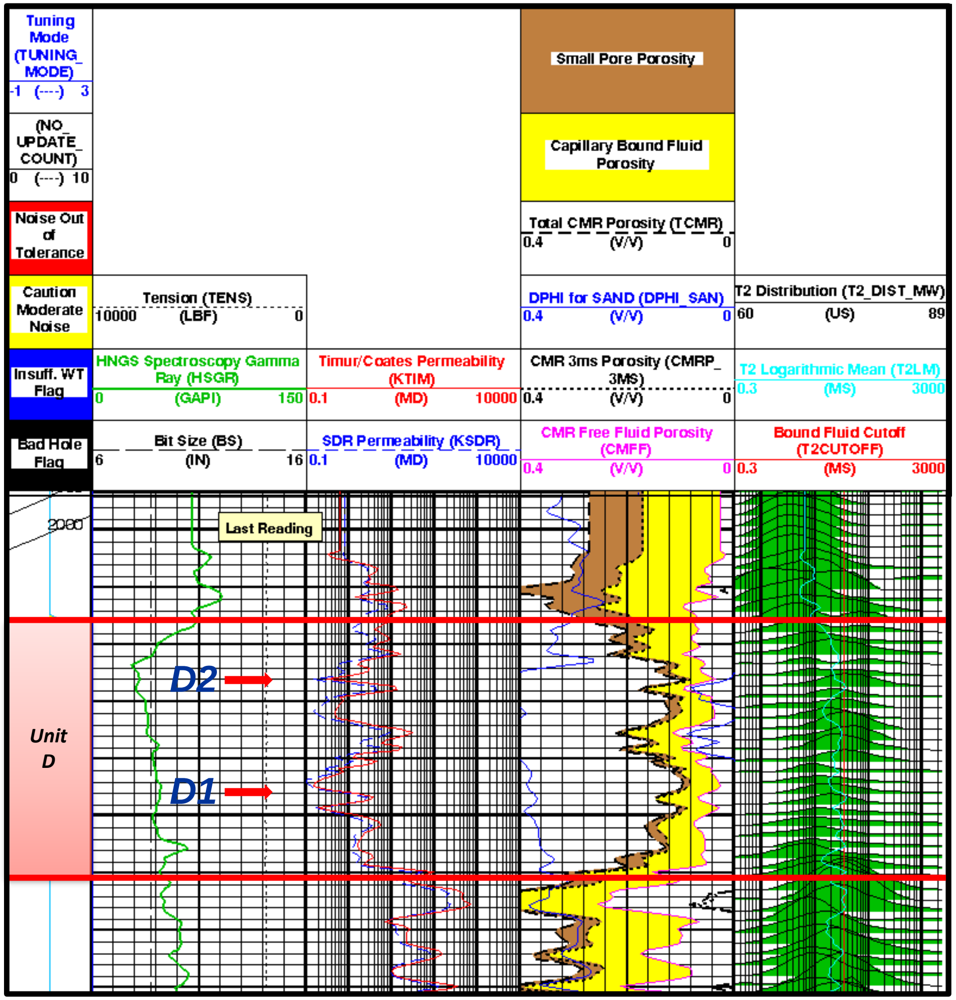


2007: BPXA Mount Elbert Gas Hydrate Stratigraphic Test

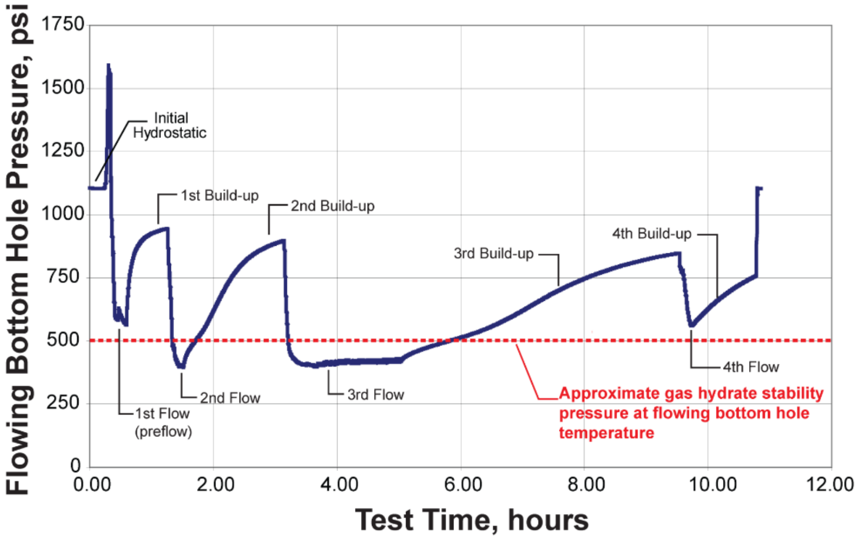
2011-2012: ConocoPhillips CO_2 Displacement Test

Alaska North Slope – Mount Elbert Well

Reservoir Properties – Effective Permeabilities



Mount Elbert 1 – Unit D



Gas Hydrate Reservoir Properties

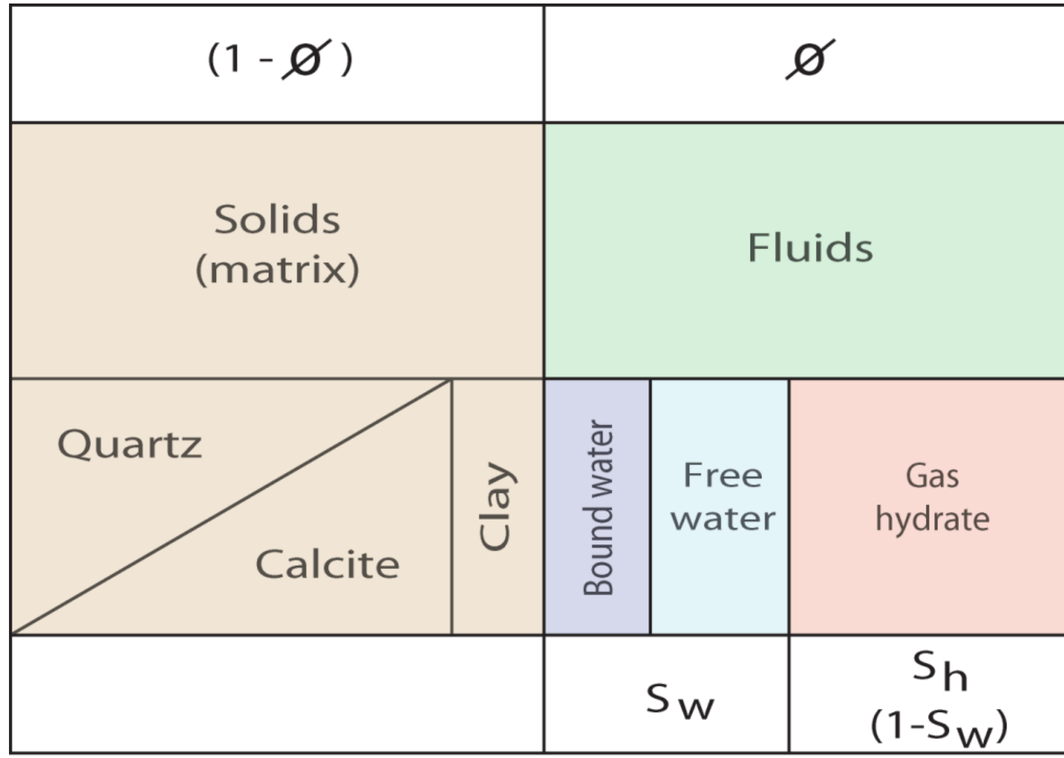
TC-SDR Effective Perm ***0.1 - 1.0 mD***

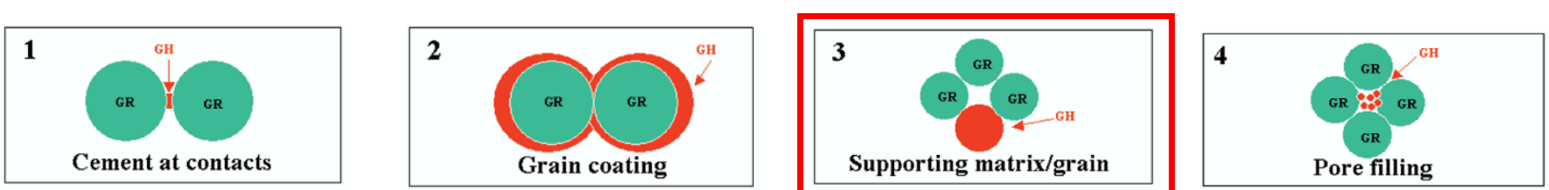
Sw 25% (15% free water, 10% bound)

MDT Effective Perm ***0.12 – 0.17 mD***

Gas Hydrate Reservoir Models

Pore-Filling (load-bearing) Growth Habit





Reservoir Properties

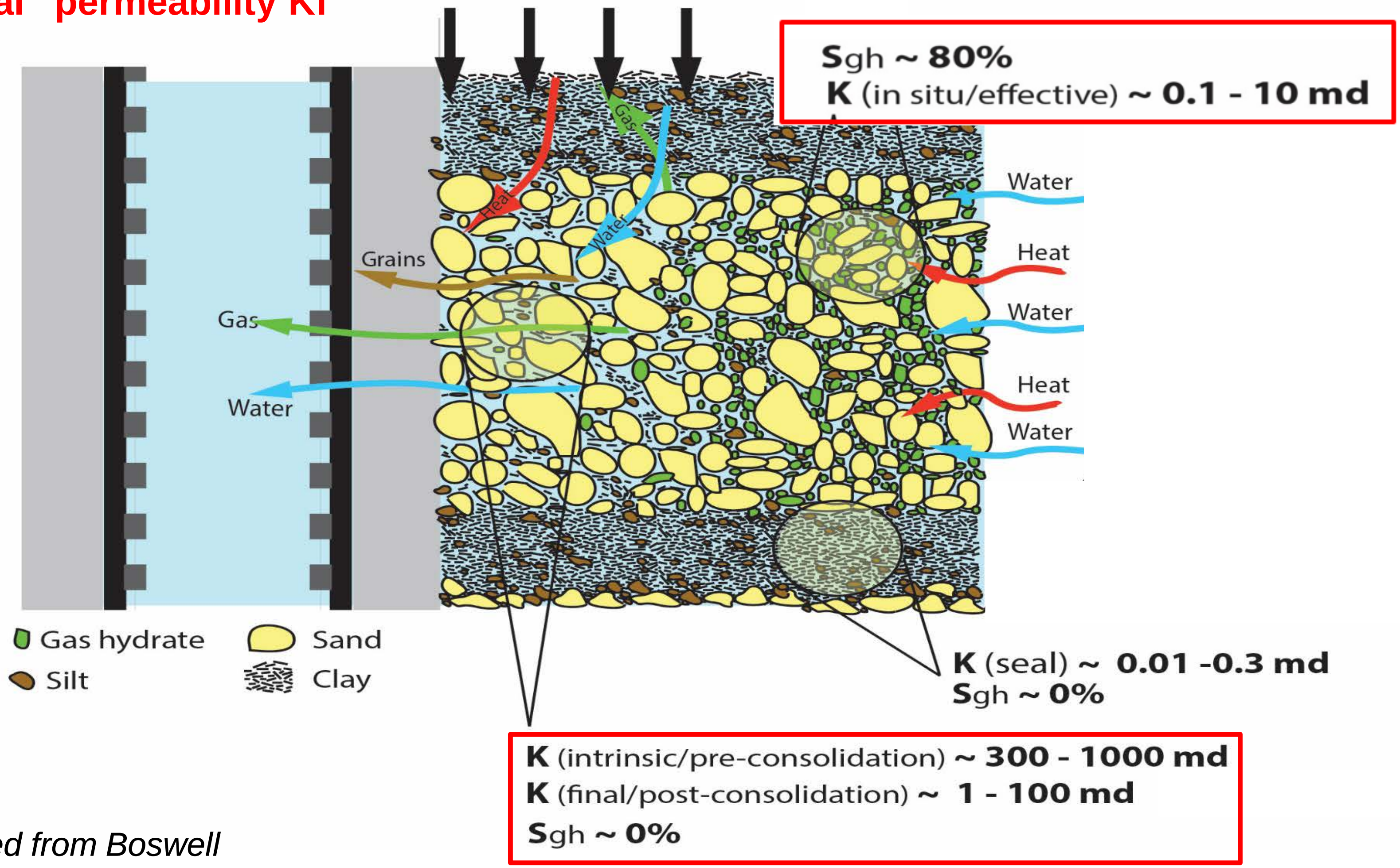
Pressure and Temperature Controls

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



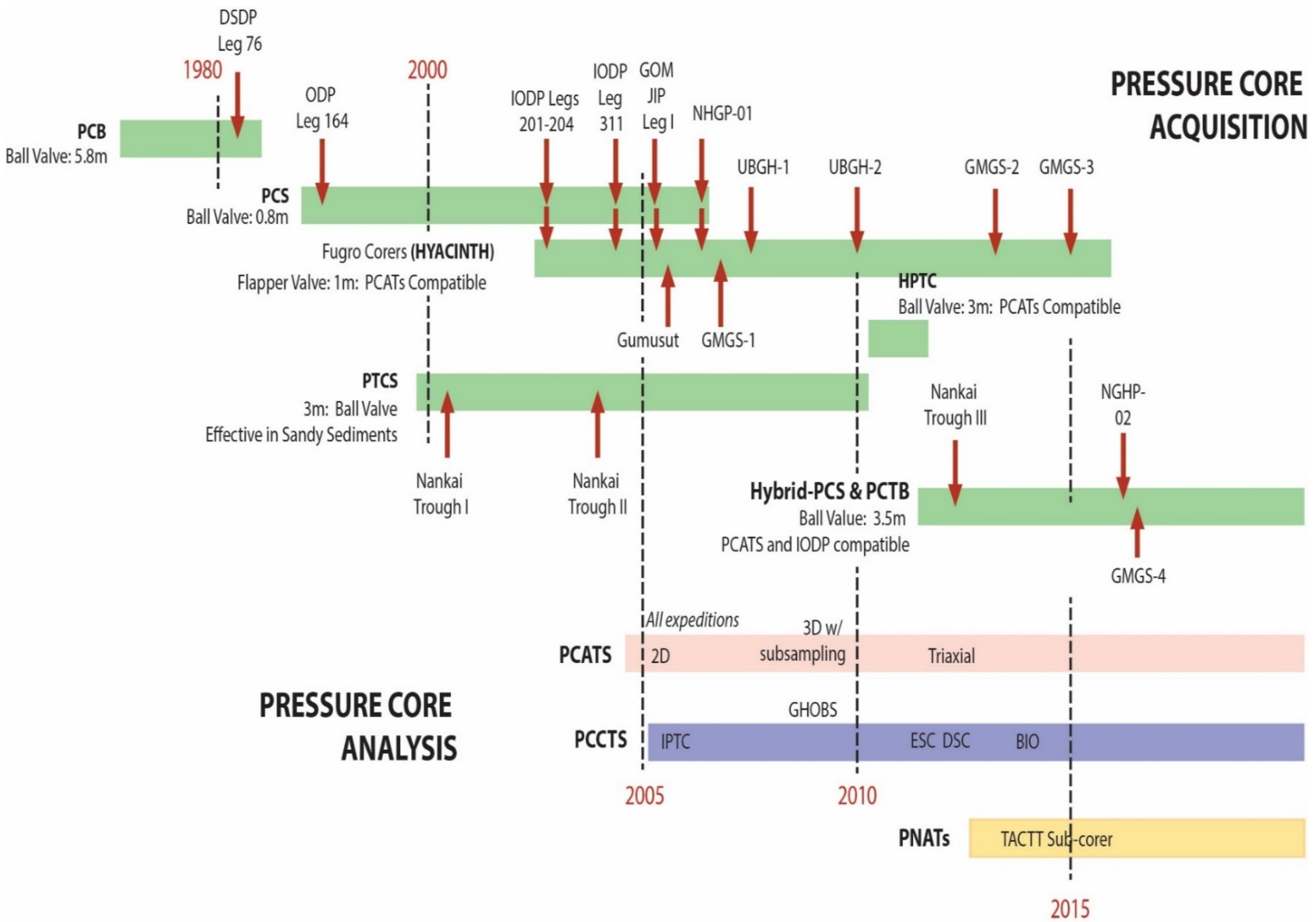
Modified from Boswell

Pressure Coring Technology

Shared designs and lessons learned over 3+ decades of pressure core development In the US, Japan, Korea, India, and China

Convergent design toward current PCTB

Alignment on common analysis tool designs

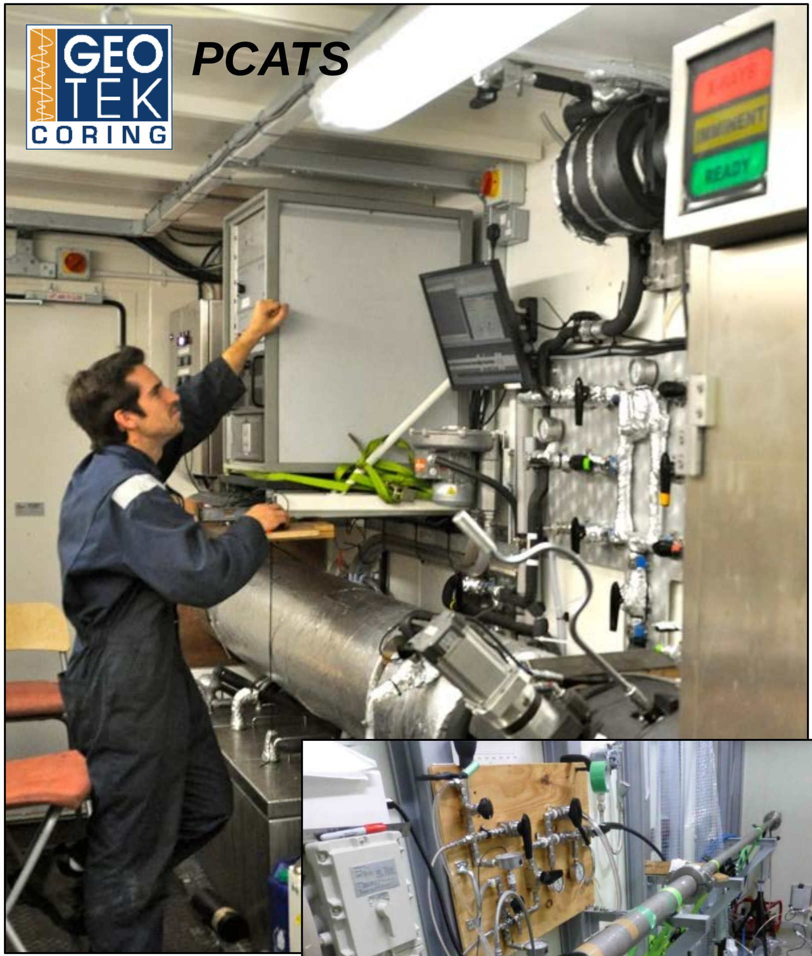


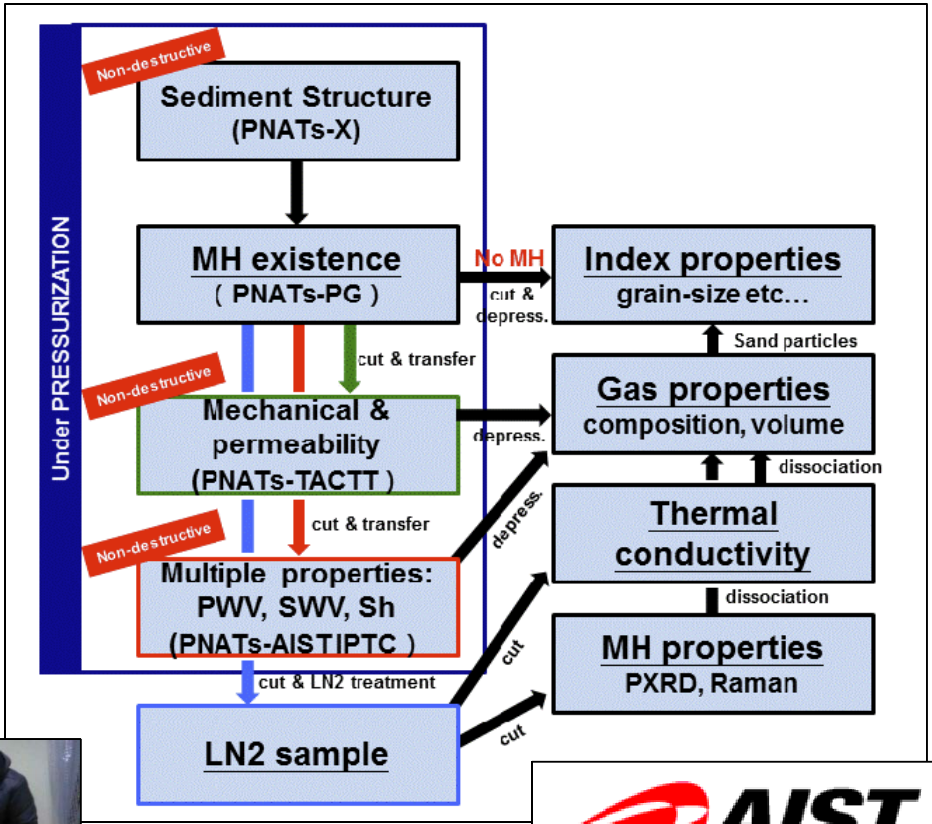
Pressure Coring Tool
Hybrid-PCS Family of Tools

- **Ball valve for full capture of all components**
- **Laboratory analysis under pressurized conditions – PCATS, AIST, USGS, UT**

Gas Hydrate Pressure Coring

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





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

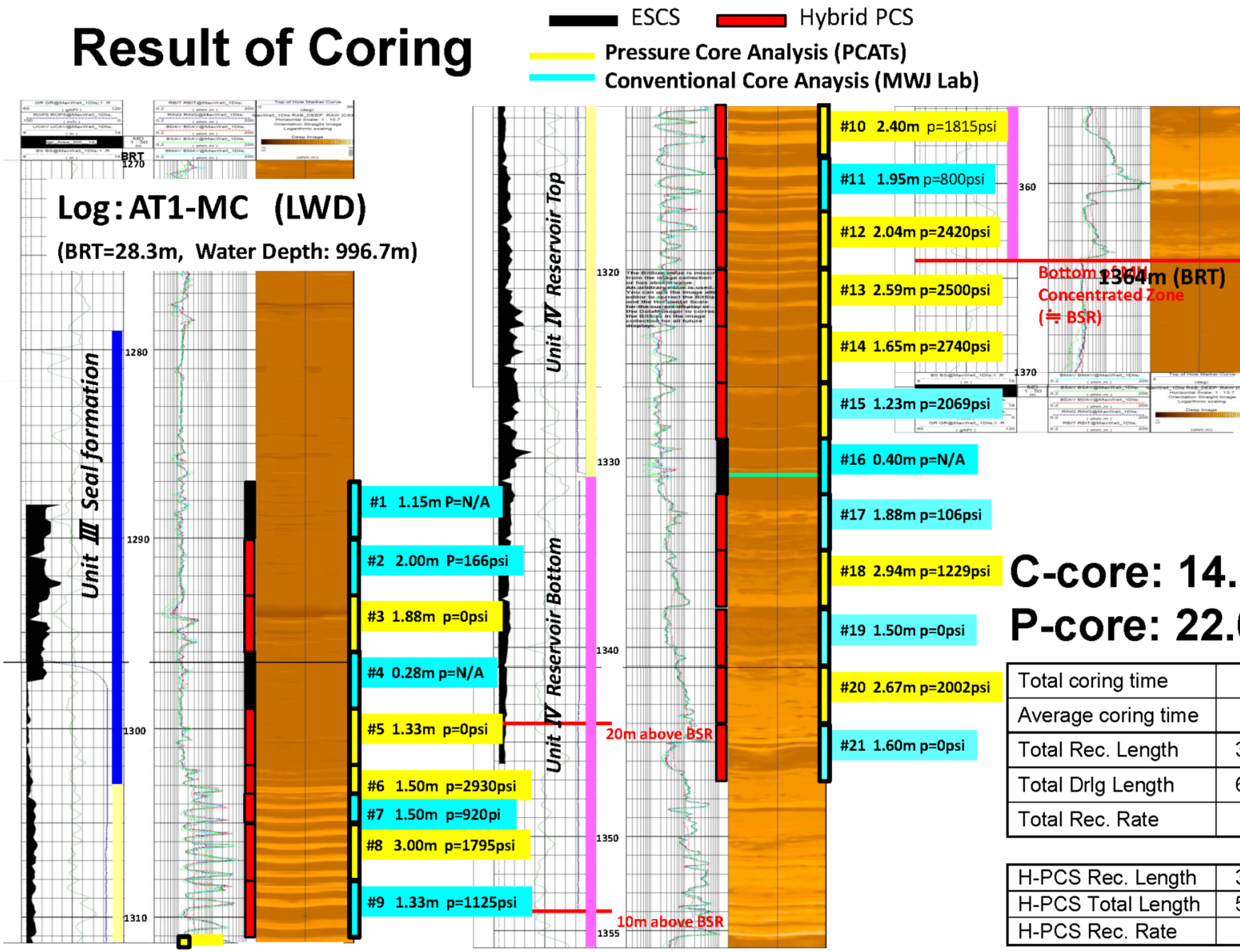
PCCTS

USGS science for a changing world

Georgia Tech

JOGMEC Gas Hydrate Pressure Coring

Result of Coring



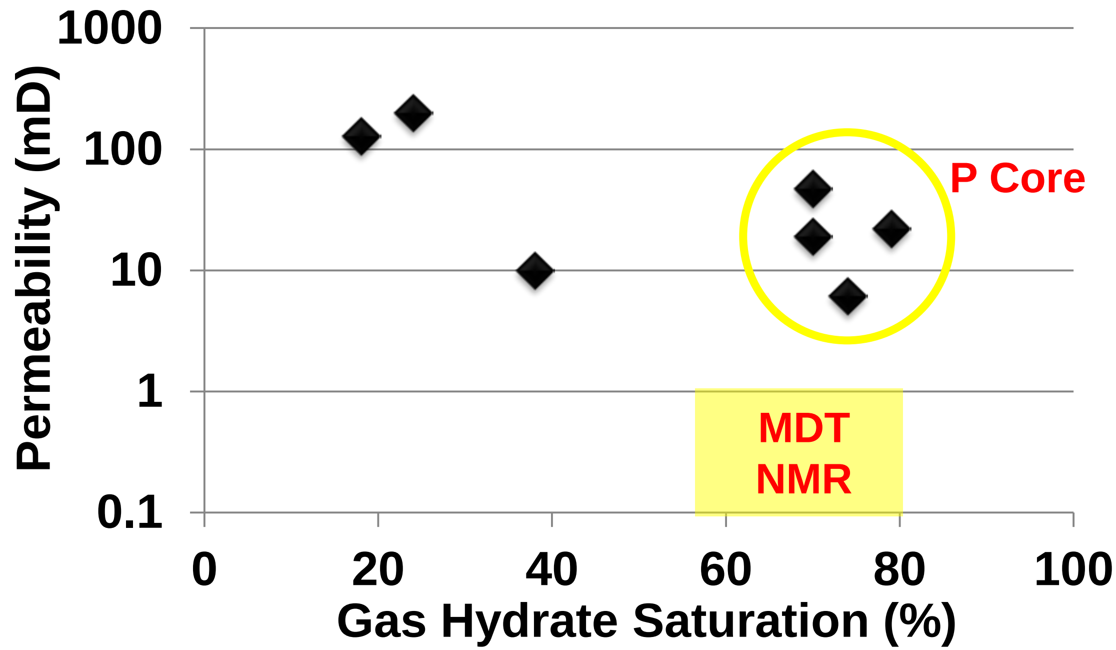
C-core: 14.82m

P-core: 22.00m

Total coring time	17:30
Average coring time	4:15
Total Rec. Length	36.82m
Total Drlg Length	60.00m
Total Rec. Rate	61%

H-PCS Rec. Length	34.99m
H-PCS Total Length	51.00m
H-PCS Rec. Rate	69%

Nankai Trough
Gas Hydrate
Pressure Core Analysis

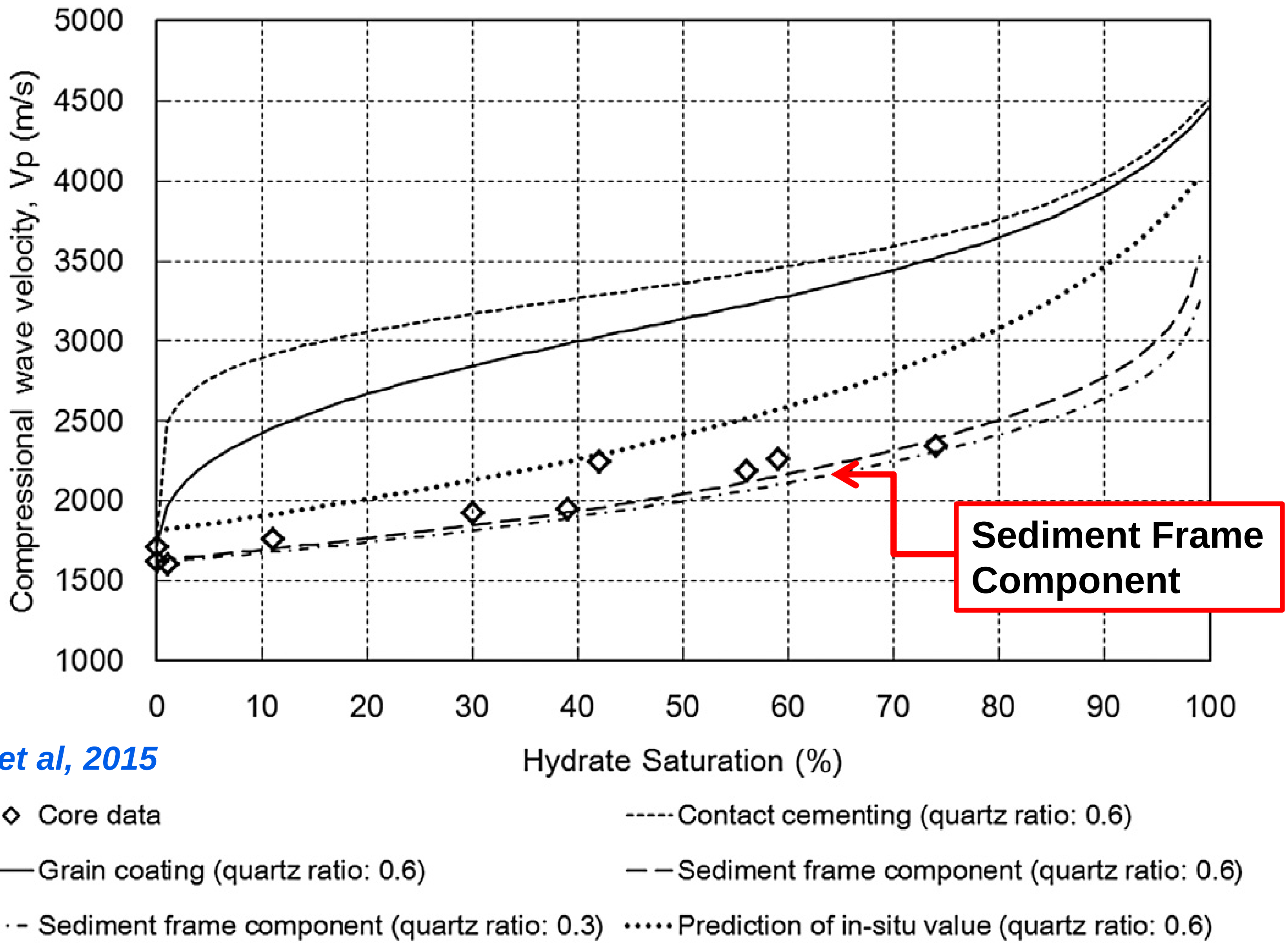


Hydrate Saturation (%)	Permeability (mD)	JMPG 2015 References
18	128	Santamarina
24	200	Konno
38	10	Yoneda
70	**47**	Konno
70	**19**	Priest
74	**6**	Santamarina
79	**22**	Yoneda

NMR log data 0.01-1.0 mD (Fujii et al., 2015)
Pressure core analysis "several tens of mD" (Konno et al., 2015)

Gas Hydrate Nankai Trough Reservoir Model

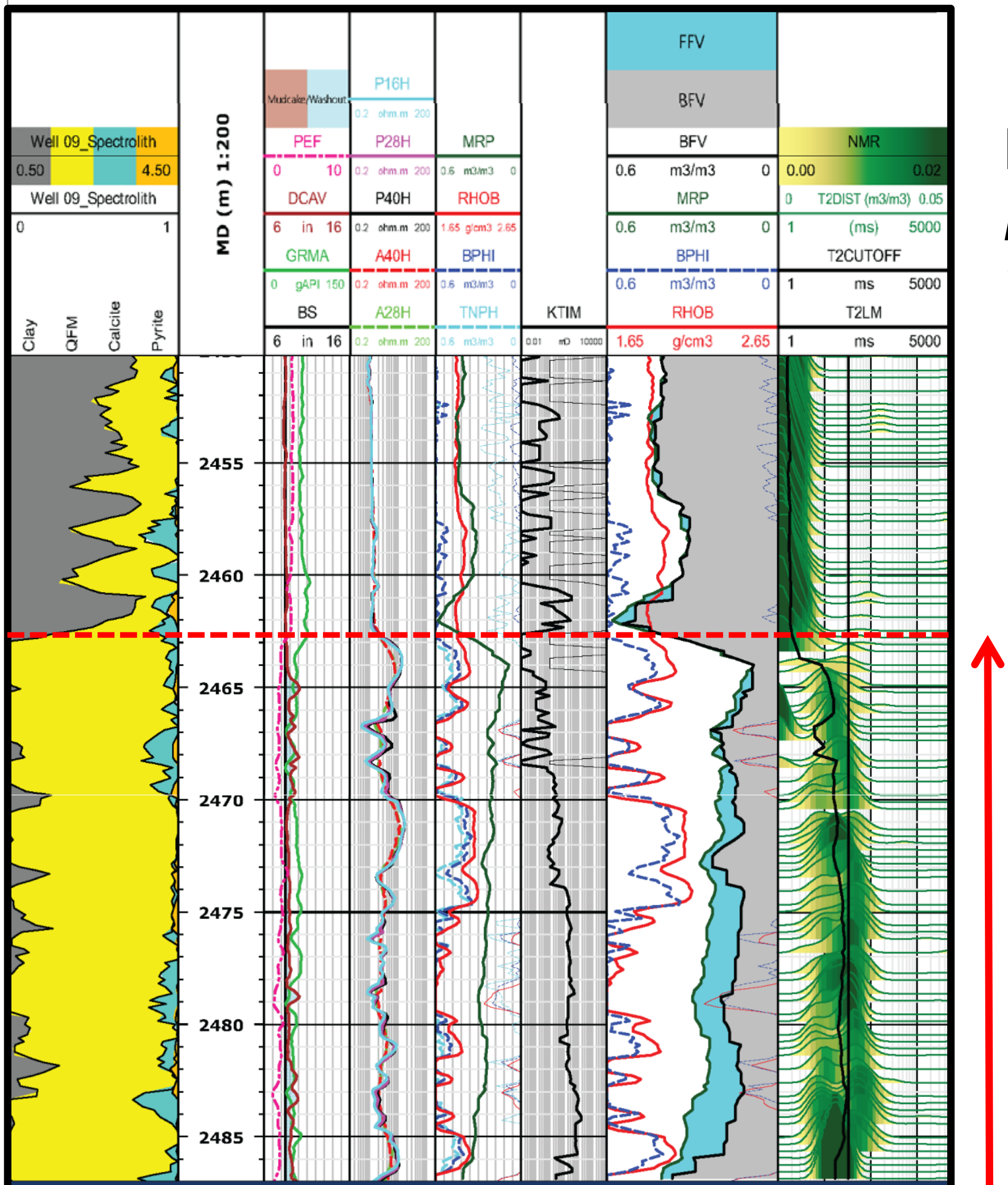
Pore-Filling (load-bearing) Growth Habit



Konno et al, 2015

ProVision Plus LWD Log

Marine Gas Hydrate Test Well



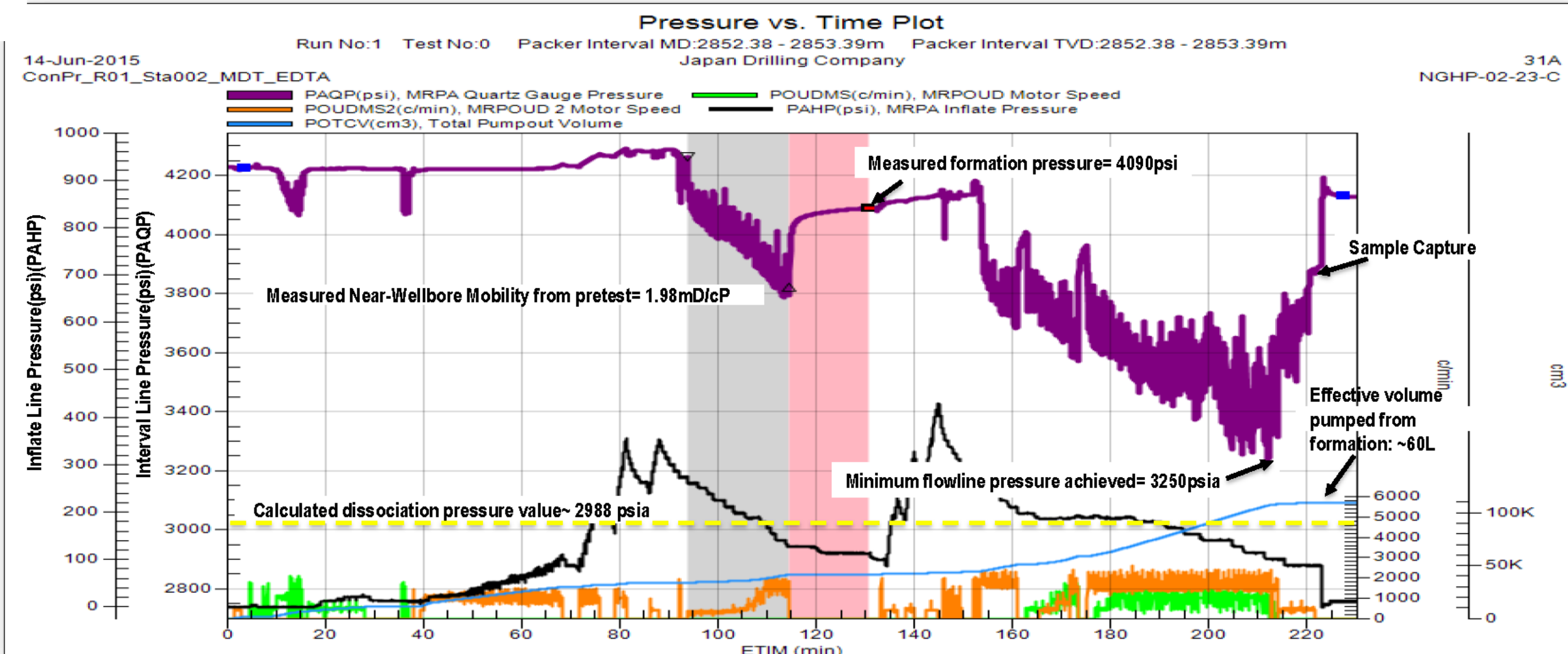
Gas-hydrate-bearing
Sand reservoir section
Sh ~ 60%
Free water phase ~ 5%
K 0.01 – 0.5 mD

Schlumberger

proVISION Plus Processing
Final Deliverables

Modular Dynamic Testing (MDT)

Marine Gas Hydrate Test Well



Packer inflation on station — Lower exit port possibly plugged due to RIH on sea bed with ROV. Troubleshooting lower pump and attempting to inflate

Drawdown — Pre-Dissocⁿ

Buildup — Pre-Dissocⁿ

Re-inflating — packers before attempting drawdown again

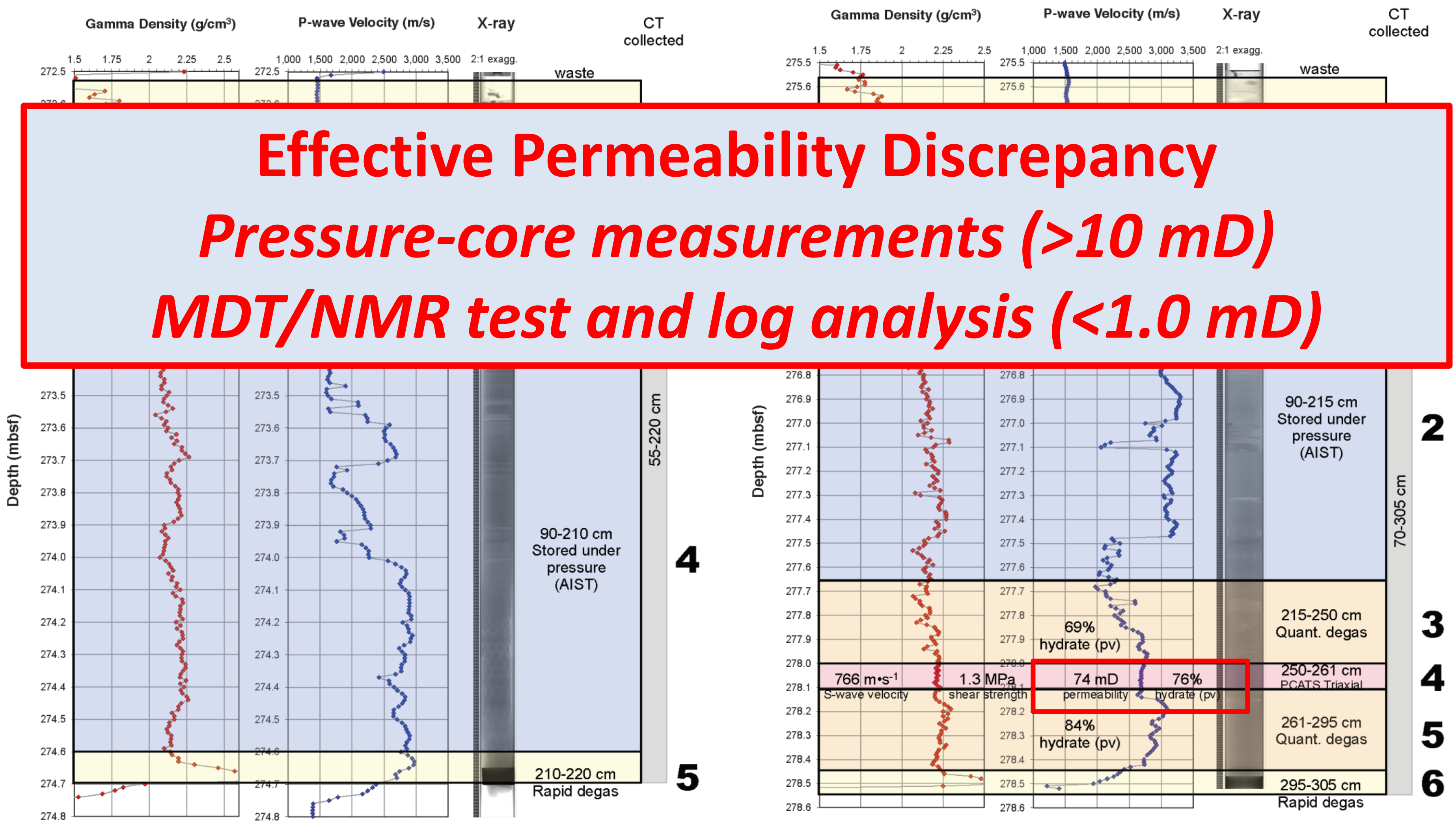
Drawdown — with both pumps at maximum speed/ constant power mode with 100% duty cycle to create maximum ΔP

Deflation

Effective Permeability: MDT test analysis (~0.1 mD)

Marine Gas Hydrate Test Well

PC – Typical GH-Bearing Reservoir Section



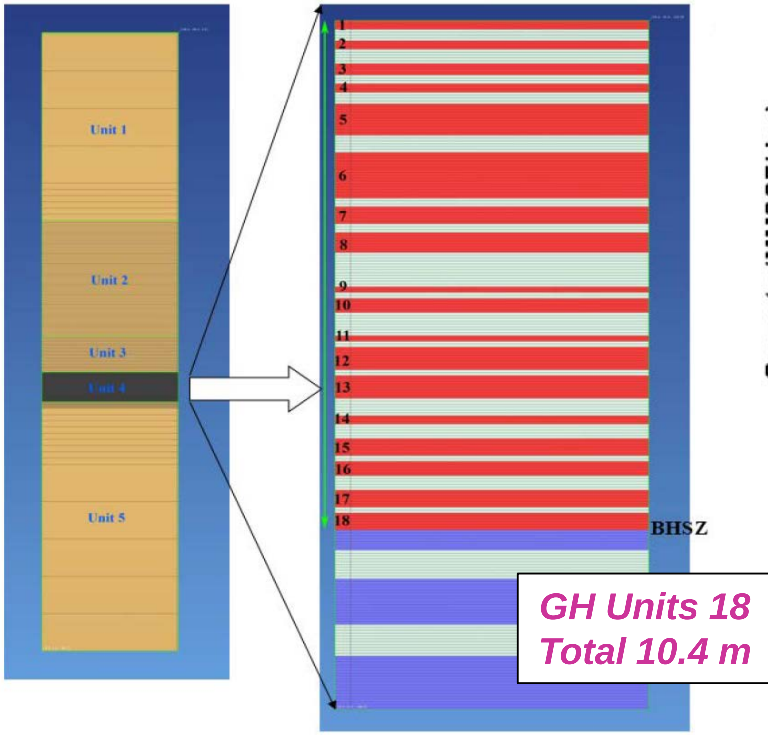
Effective Permeability Discrepancy

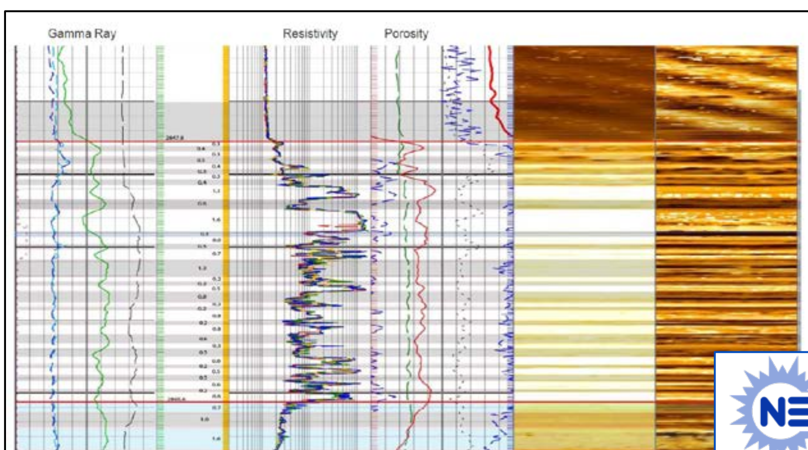
Pressure-core measurements (>10 mD)

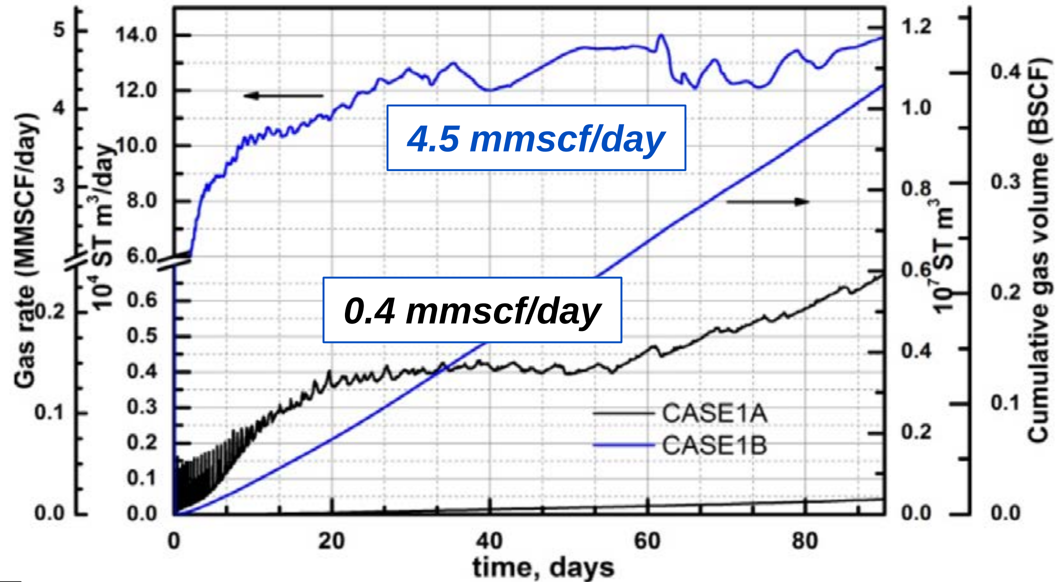
MDT/NMR test and log analysis (<1.0 mD)

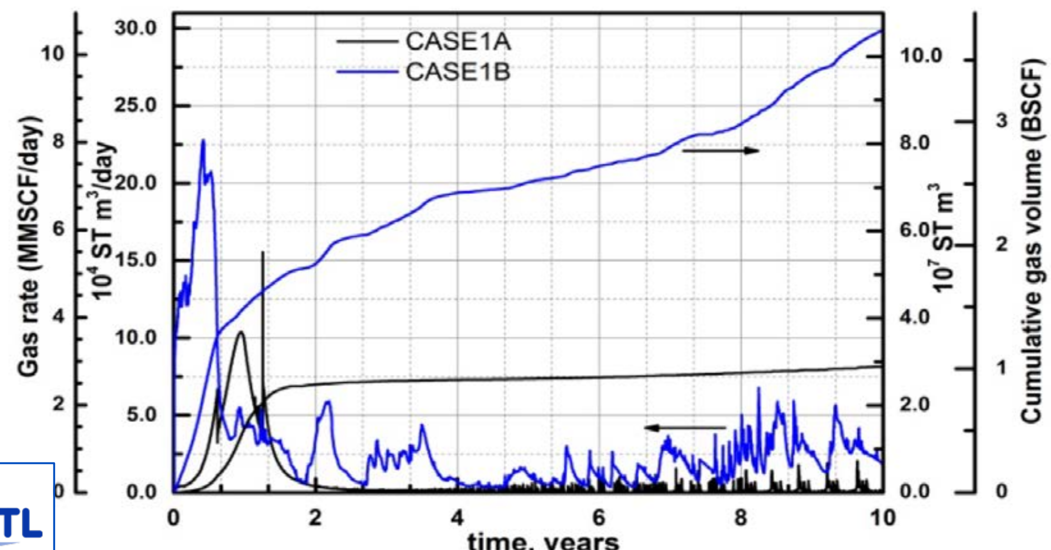
GH Production Modeling – Permeability Uncertainty

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









NETL

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 Arctic permafrost related scientific field tests, additional marine tests in China, Japan, and planned for 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