Alaska Natural Gas Hydrate Production Testing, Test Site Selection, Characterization and Testing Operations

Project Number DE-FE0022898

Timothy S. Collett

United States Geological Survey

U.S. Department of Energy

National Energy Technology Laboratory

Oil & Natural Gas

2020 Integrated Review Webinar

Program Overview

- Funding:
  DOE $230,700
  USGS $1,890,000 (Cost Share)
- Overall Project Performance Dates
  09/01/2014 – 01/15/2021
- Project Participants
  Tim Collett, USGS (PI)
  Seth Haines, USGS
  Rita Zyrianova, USGS
  Sam Heller, USGS
  Krissy Lewis, USGS

Overall Project Objective

The objective of this Department of Energy (DOE) and the United States Geological Survey (USGS) Interagency Agreement (IA) is to provide geologic and geophysical technical support to identify and characterize gas hydrate production test sites on the Alaska North Slope and to develop plans for an extended gas hydrate production testing program. This project is designed as a cooperative research effort, with USGS providing technical geoscience support in a partnership that includes DOE and the Japan Oil, Gas and Metals National Corporation (JOGMEC).

Technology Background

The primary goal of this cooperative project is to conduct a scientific field production test in northern Alaska from one or more gas hydrate bearing sand reservoirs using conventional "depressurization" technology. The project will include the drilling and evaluation of a stratigraphic test well (completed in December 2018), followed by the establishment of a production test site (including a geoscience data well, two production test wells, deployment of well monitoring systems, and surface monitoring), and the testing of reservoir response to pressure reduction over a period of about 12 months or for whatever period the parties find operations at the site to be valuable.

Technical Approach/Project Scope

Phase 1

Original Award (09/01/2014 – 12/31/2015)

Task 1: Gas Hydrate Production Testing Support

Subtasks 1.1: Geologic occurrences of gas hydrate, analyzing available Eileen geologic and geophysical data

The USGS shall refine current interpretations of the regional Alaska North Slope gas hydrate stability field as well as the distribution and properties of previously-identified gas hydrate accumulations in the Eileen Gas Hydrate Trend through the collection and incorporation of new well log and seismic data.

Subtask 1.2: Gas hydrate field test technical and operational support

The objectives of this subtask are to: (1) provide technical and scientific leadership and advice for formulation of a research drilling and production testing program designed to assess the nature and production potential of gas hydrates on the Alaska North Slope; (2) provide personnel and resources to enhance field and laboratory analyses of material recovered (under separate DOE projects) by conventional and pressure core systems; and (3) partner in the synthesis of data from logging, direct sampling, and geophysical and geologic characterization studies conducted under separate DOE projects.

Technical Approach/Project Scope

Phase 2

Mod-1 (01/01/2016 – 12/31/2016)

Mod-2 (12/31/2016 – 12/31/2017)

Task 2: Gas Hydrate Production Testing Support (continued)

Subtask 2.1: Geologic occurrences of gas hydrate, analyzing available Eileen geologic and geophysical data

The general goals of this subtask are the same as those identified in Subtask 1.1 with the USGS leading the geoscience aspects of the DOE sponsored effort to conduct an extended gas hydrate production test on the Alaska North Slope. The specific focus of USGS geologic studies shall expand to further characterize two additional high priority potential gas hydrate test sites for consideration of testing: The Milne Point Unit Cascade site and Prudhoe Bay Unit Kuparuk 7-11-12 site.

Subtask 2.2 Gas hydrate field test technical and operational support

USGS shall work with DOE, who will coordinate with JOGMEC, and Petrotechnical Resources of Alaska (PRA), to generate a preliminary plan for the long-term gas hydrate production test in northern Alaska with a specific emphasis on identifying and designing the data acquisition requirements for the proposed test well program. The USGS shall provide DOE the reservoir data needed to model the production response of the gas hydrate accumulations being considered for testing.

Technical Approach/Project Scope

Phase 3

Mod-3 (09/01/2014 – 12/31/2018)

Task 3: Gas Hydrate Production Testing Support (continued)

Subtask 3.1: Geologic occurrences of gas hydrate, analyzing available Eileen geologic and geophysical data

The general goals of this subtask are the same as those identified in Subtasks 1.1 and 2.1. During the DOE planned site review and appraisal project stage the USGS shall work with DOE and appropriate project interest groups to conduct a detailed geologic and geophysical analysis of the Prudhoe Bay Unit Kuparuk 7-11-12 site.

Subtask 3.2 Gas hydrate field test technical and operational support

USGS shall work with DOE to develop a plan for the long-term gas hydrate production test in northern Alaska with a specific emphasis on identifying and designing the data acquisition requirements for the proposed test well program. The USGS shall contribute to the development of an integrated project "Statement of Requirements" (SOR) for the proposed test well program. The USGS shall work with providers to develop both distributed and gauge-based wellbore monitoring systems to evaluate the potential contribution of these systems to the Alaska North Slope gas hydrate test program.

Technical Approach/Project Scope

Phase 4

Mod-4 (09/01/2014 – 8/31/2019)

Mod-5 (09/01/2014 – 6/1/2020)

Mod-6 (09/01/2014 – 1/15/2021)

Task 4: Gas Hydrate Production Testing Support (continued)

Subtask 4.1: Geologic occurrences of gas hydrate, analyzing available Eileen geologic and geophysical data

The general goals of this subtask are the same as those identified in Subtasks 1.1, 2.1, and 3.1. During this performance period it is expected that the field phase of this project shall start with the drilling of the stratigraphic test well to verify the viability of the PBU Kuparuk 7-11-12 production test site. The USGS shall contribute to the acquisition, processing, and analysis of well log data sets and sidewall cores.

Subtask 4.2 Gas hydrate field test planning technical and operational support

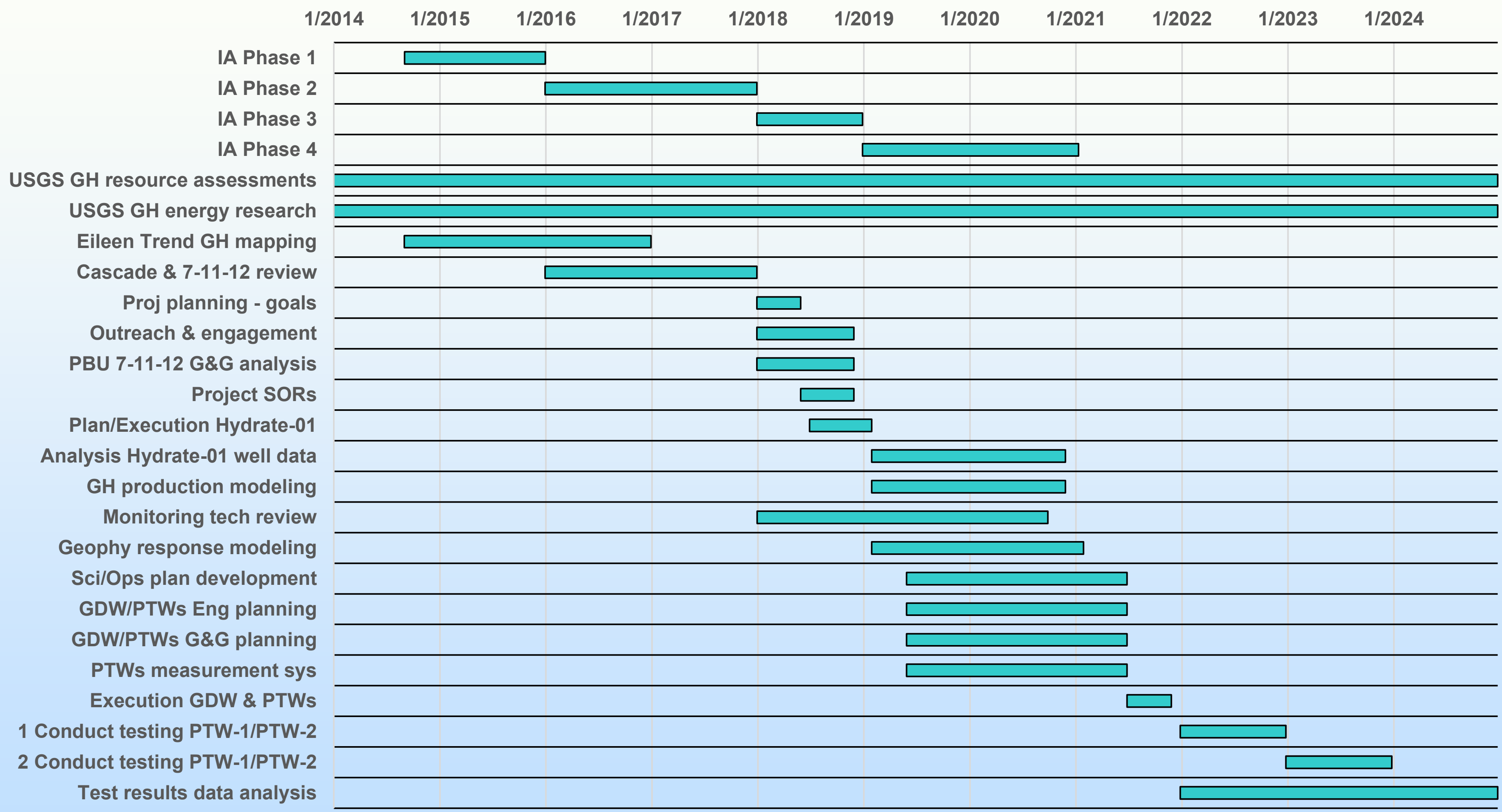
The USGS shall work as a member of the newly formed project “R&D Committee” to review and modify the existing operational plan in support of the “Alaska Gas Hydrate Production Field Experiment” well test plan, incorporate results of the recently completed Hydrate-01 Stratigraphic Test Well and other international gas hydrate production testing projects.

Progress and Current Status

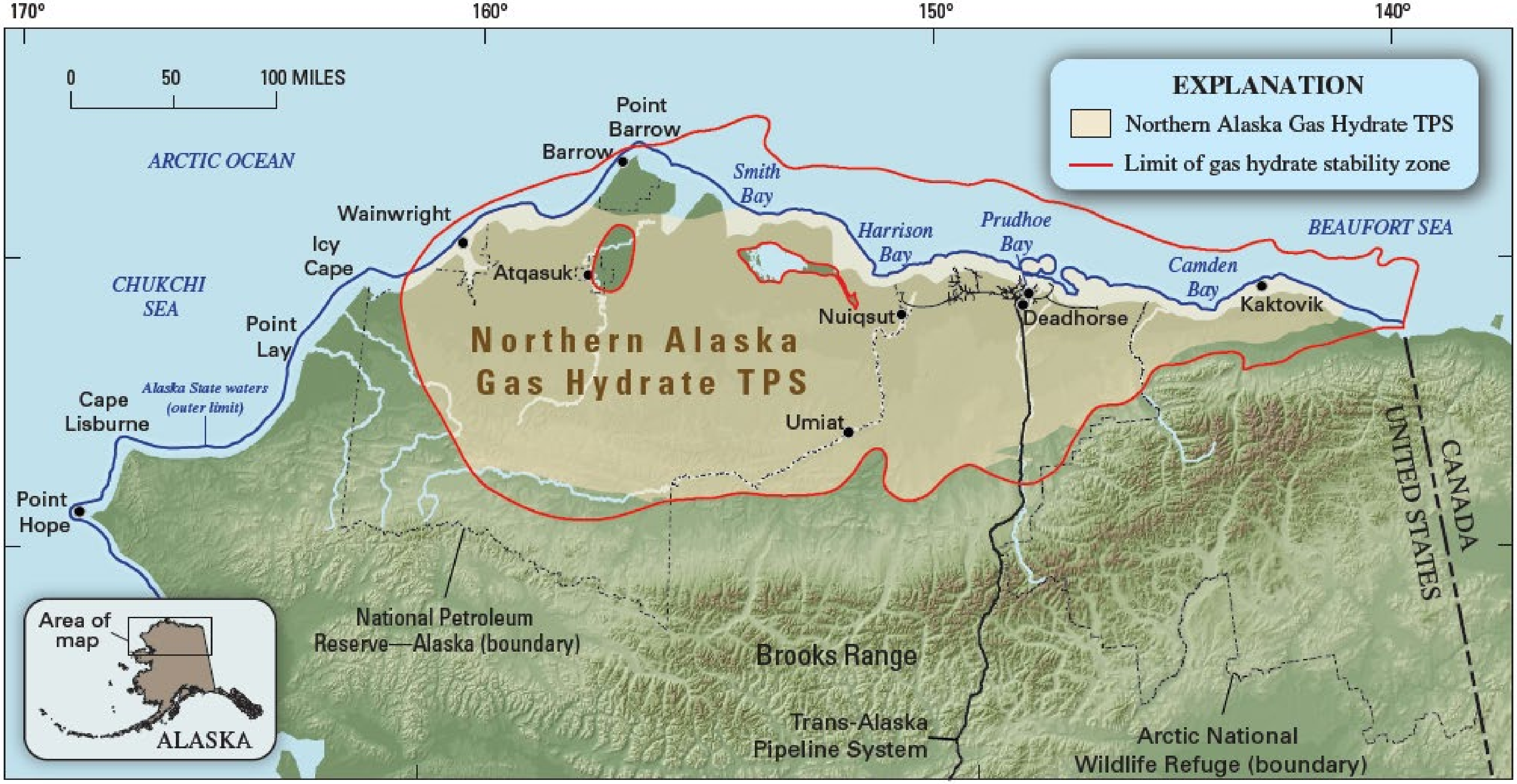
Alaska Gas Hydrate Production Field Experiment – Planning and Accomplishments

- USGS research and resource assessments in Alaska
- Gas hydrate production testing interest in Alaska – Before 2016
- Mapping and characterization of gas hydrate accumulations in the Eileen Trend
- Production test site G&G analysis and selection – MPU Cascade and PBU 7-11-12
- Development of the initial goals of the Alaska Gas Hydrate Production Field Experiment
- Public and private sector outreach and engagement in Alaska
- Detailed G&G and reservoir engineering examination of the PBU 7-11-12 Test Site
- Development science and operational project plans and task specific Statements of Requirements
- Planning and execution of the Hydrate-01 Stratigraphic Test Well drilling program
- Analysis of geologic (well logs and core derived) and geophysical data acquired from the Hydrate-01 well
- Gas hydrate production modeling studies with data from the Hydrate-01 well
- Production testing monitoring technology R&D review – distributed and gauge-based systems
- Gas hydrate geophysical response modeling – focus on 3D/4D VSP acquisition, processing, and analysis
- Development of the Alaska Gas Hydrate Production Field Experiment Science and Operational Plan
- Development of the GDW/PTWs well delivery, completion, monitoring, and production testing plans
- Development of the GDW and PTWs G&G and production testing data (logging, coring, geophysical, monitoring, etc.) acquisition and analysis plan
- Review and development of well response systems to measure produced fluid/gas volumes and P/T responses with surface and down hole equipment
- Execution of the Geoscience Data and Production Test wells drilling and data acquisition program
- Conduct production testing in PTW-1 and as appropriate in PTW-2 consisting of pressure reduction and monitoring, with intervention as needed and surface operations including gas, water, and solids disposal
- Test results data analysis, post-testing production modeling code calibration studies, and reporting

ANS GH Testing - Gantt Chart



USGS Alaska North Slope Gas Hydrate Research
Gas Hydrate Assessments & Production Studies



1983-2020: USGS Alaska North Slope Gas Hydrate Assessment Project
2007: BPXA Mount Elbert Gas Hydrate Stratigraphic Test
2011-2012: ConocoPhillips CO_2 Displacement Test
2018-2024: Alaska North Slope Extended GH Production Test

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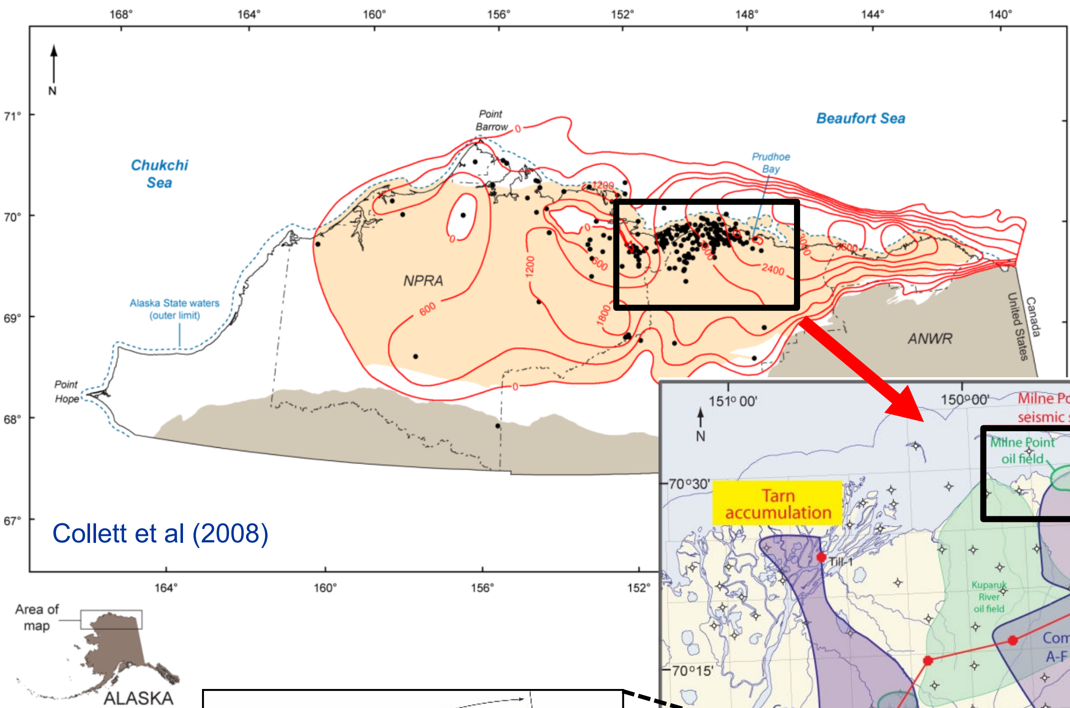
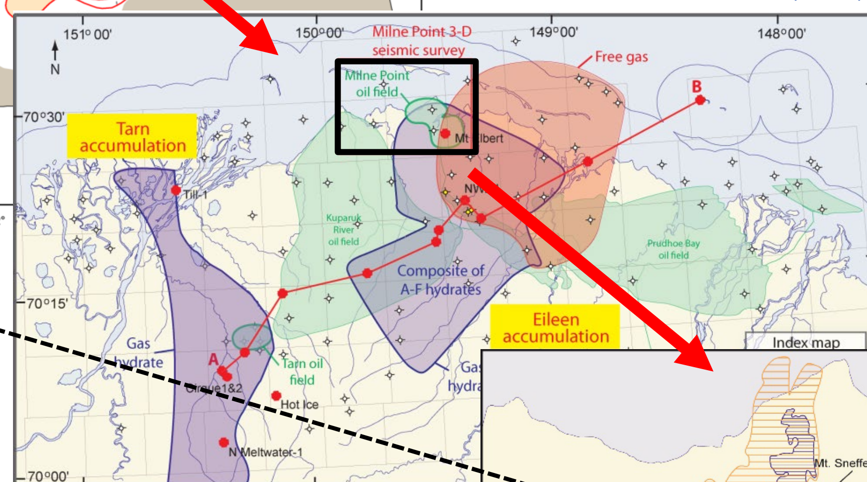
USGS Alaska North Slope Gas Hydrate Research

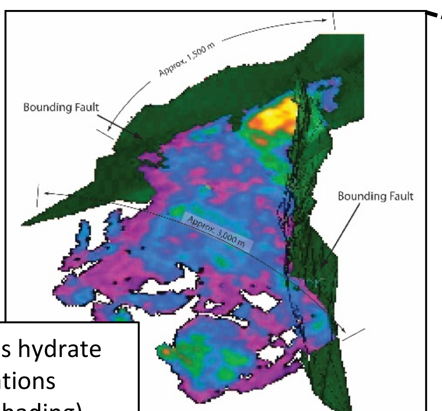
Gas Hydrate Petroleum System Analysis



Collett et al (2008)

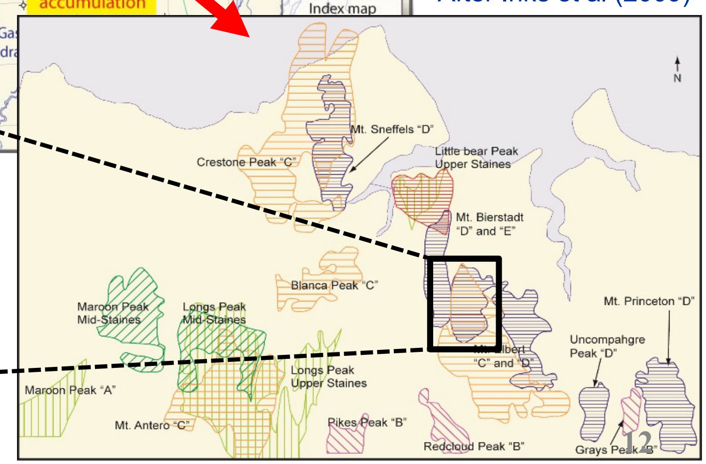
Collett (2002)





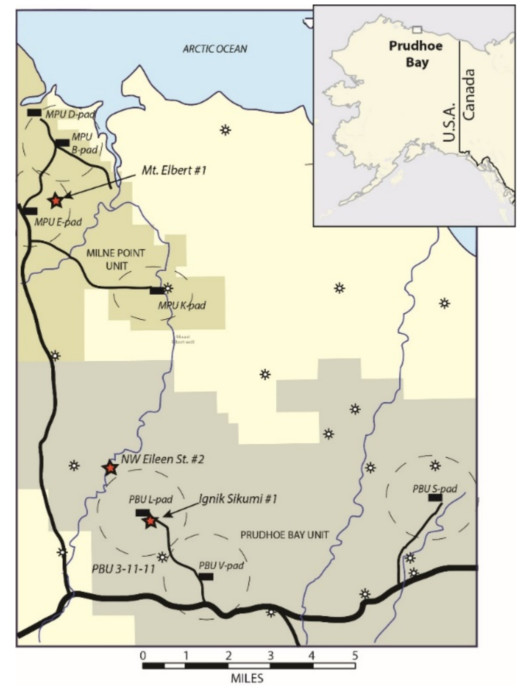
Highest gas hydrate saturations (yellow shading)

After Inks et al (2009)



Gas Hydrate Energy Studies in Alaska and Canada
Production Testing Interest before 2016

- **Evidence for the occurrence of gas hydrate in the Arctic reported since the 70s** (West Siberia, Alaska North Slope, Mackenzie Delta)
- **1970s: Industry Drill-Stem Testing** (Alaska North Slope, Mackenzie Delta)
- **1998, 2002: Mackenzie Delta - Mallik** (ice pad: G&G effort and successful wireline depressurization test and thermal stimulation test)
- **2004: Hot Ice Project** (failed G&G effort)
- **2007: MPU Mount Elbert Project** (ice pad: G&G effort and successful wireline depressurization test)
- **2006-07: Mackenzie Delta - Mallik Test** (ice pad: successful depressurization demonstration)
- **2011-12: PBU Iġnik Sikumi injection & depressurization testing** (ice pad: G&G effort and successful displacement and depressurization test)
- **2014-2015: US-Japan AK State Lands Review (w/ DNR)** (unacceptable geologic and operational risks)



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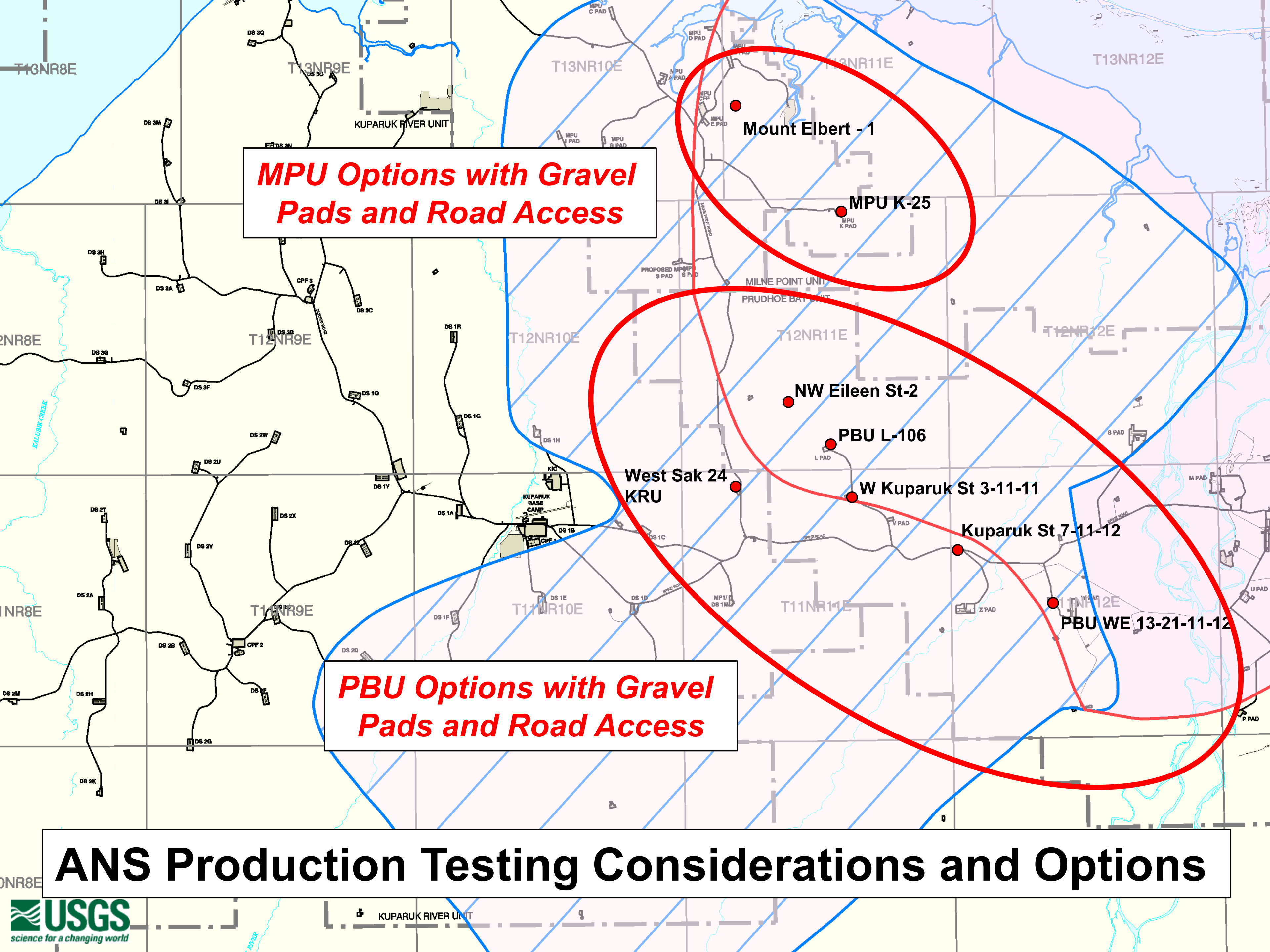

ANS Production Testing Considerations and Options

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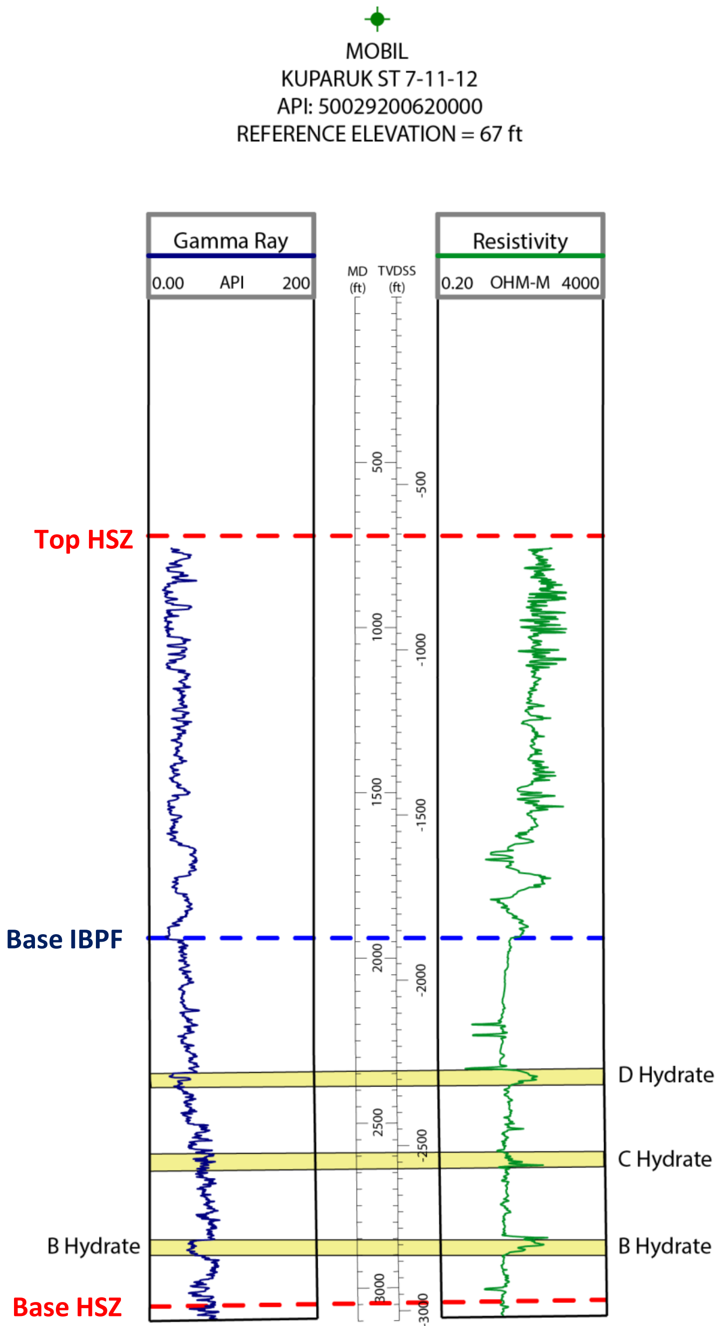

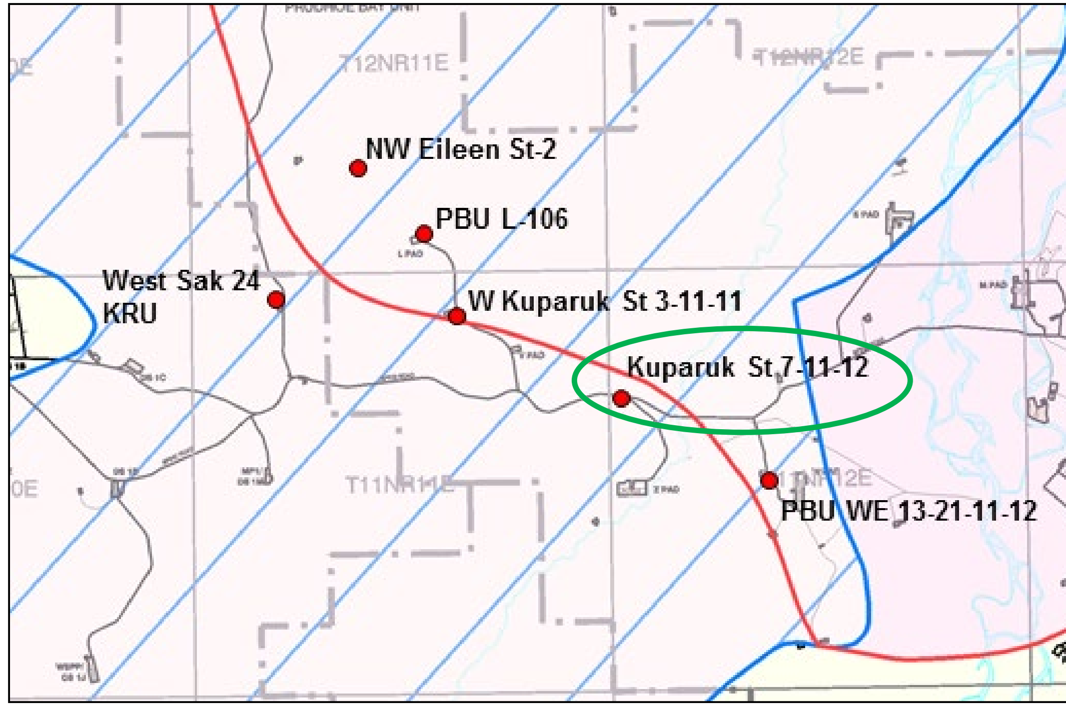

Kuparuk State 7-11-12

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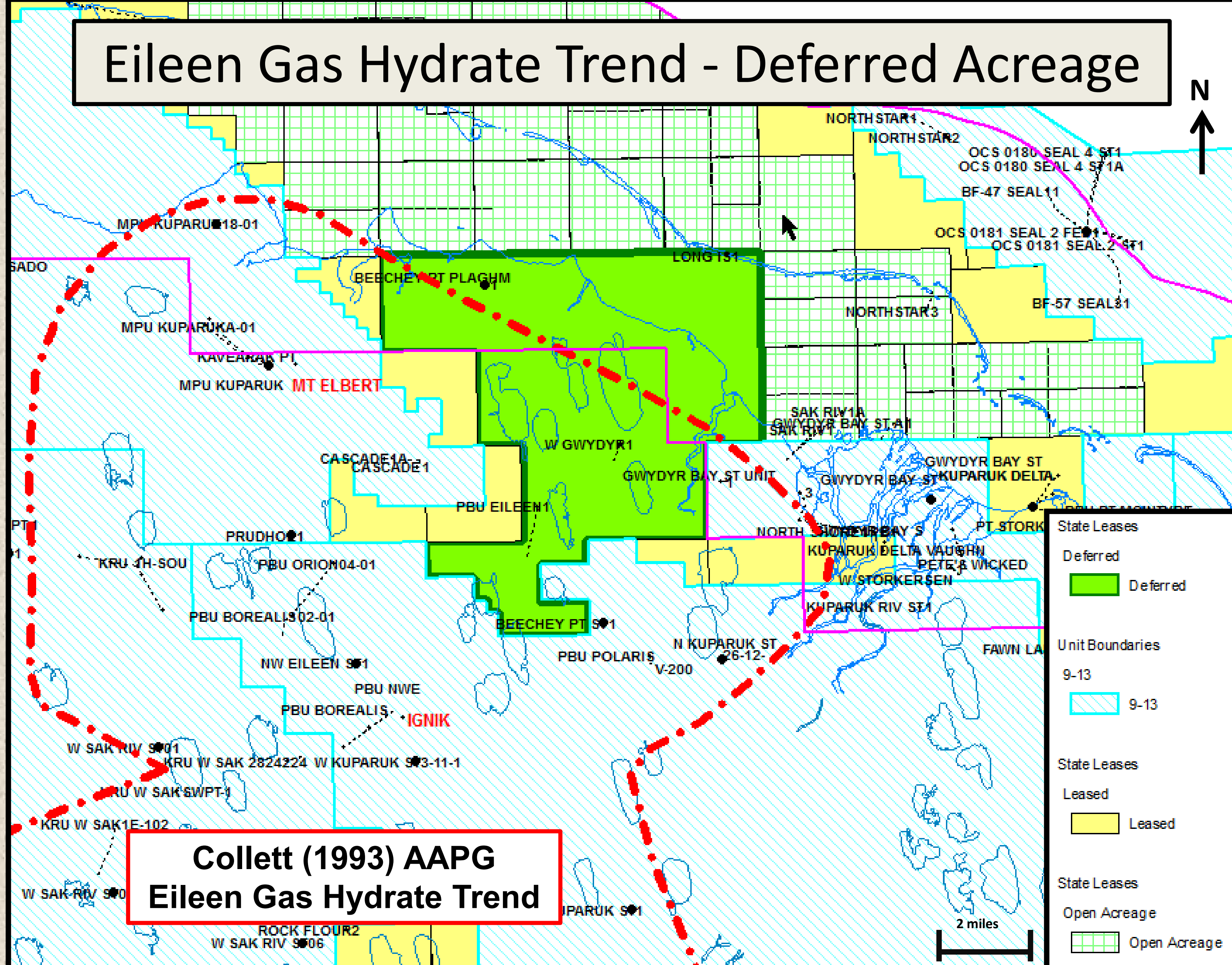
Eileen Gas Hydrate Trend - Deferred Acreage

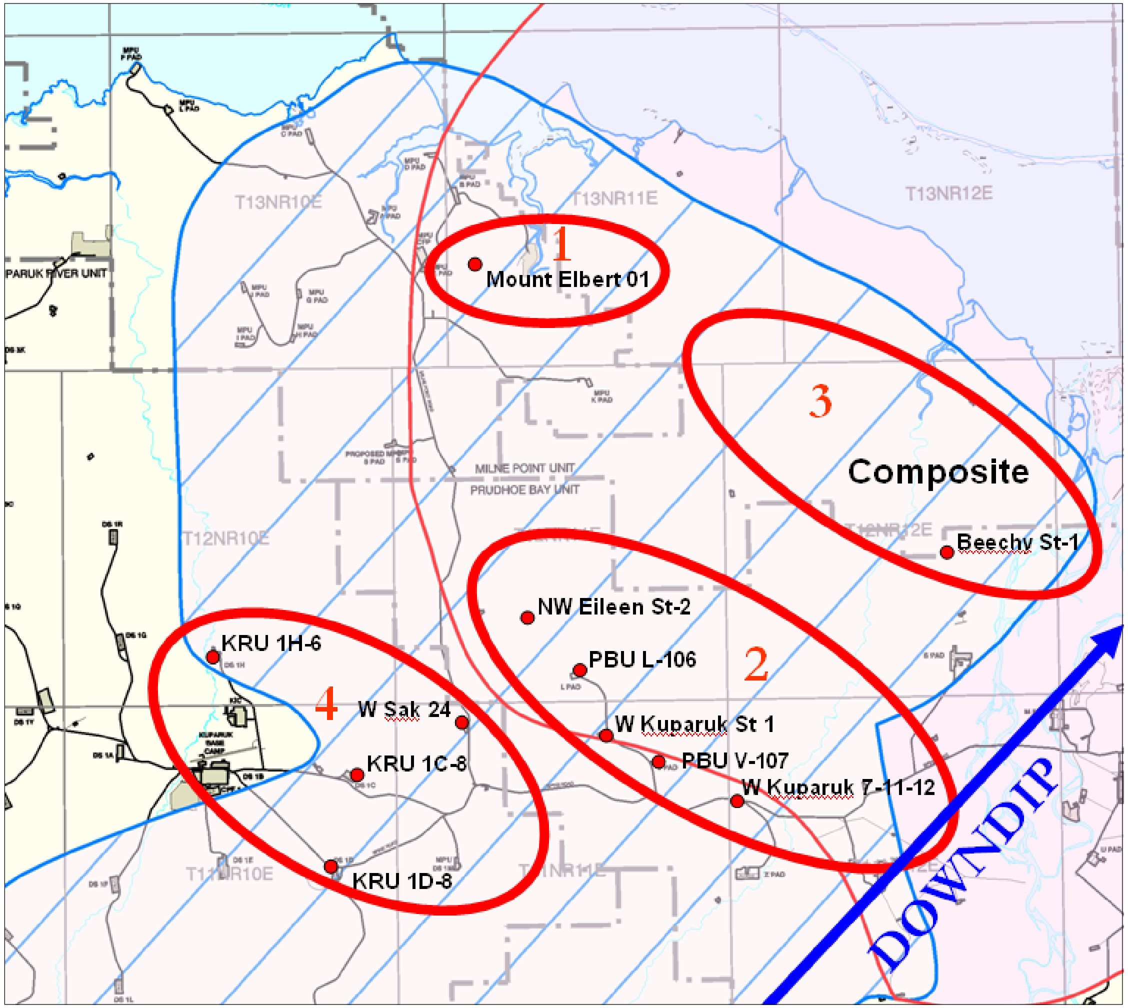


Long-Term Depressurization Testing

Four Areas Were Initially Considered – PBU KRU MPU

Key Criteria

- **Probability for test success**
  - Reservoir presence & quality
  - Temperature
  - Nature of contacting units (pressure support?)
  - Modeling results
  - Operational flexibility (multiple zones)
- **Ease of Access**
- **Logistics/Facilities**
- **Program Complexity**

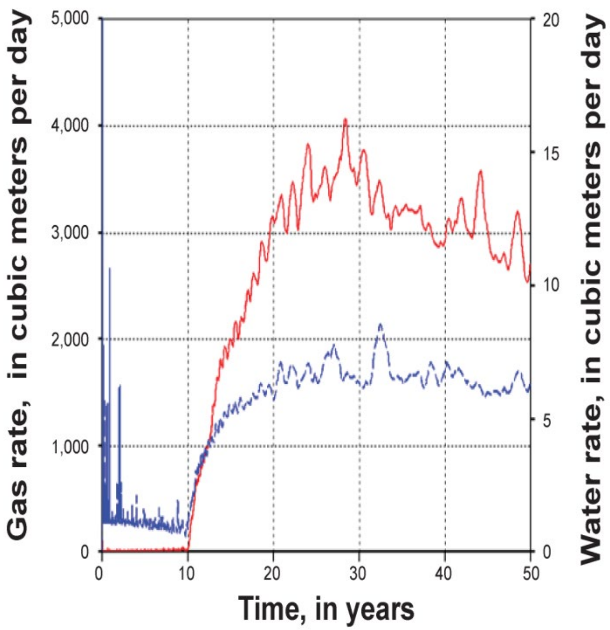


Long-Term Depressurization Testing

Scenarios for Modeling Comparison – MPU and PBU

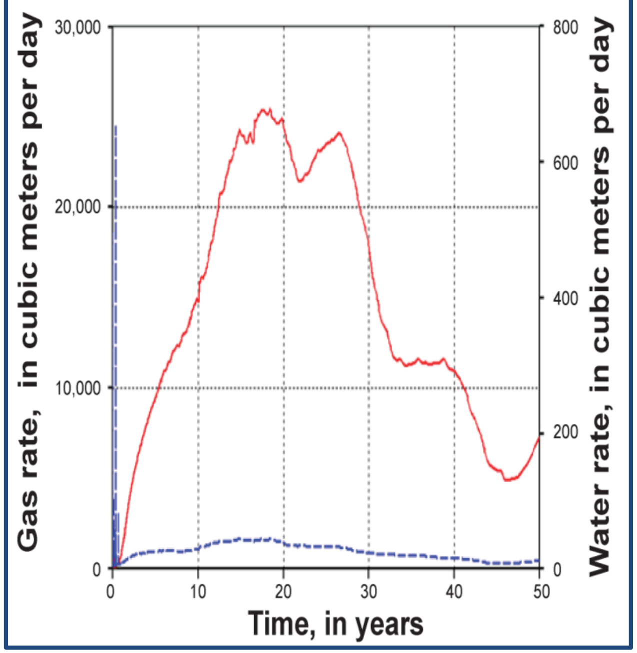
Mt Elbert (2-3 °C)

>4,000 m^3/day



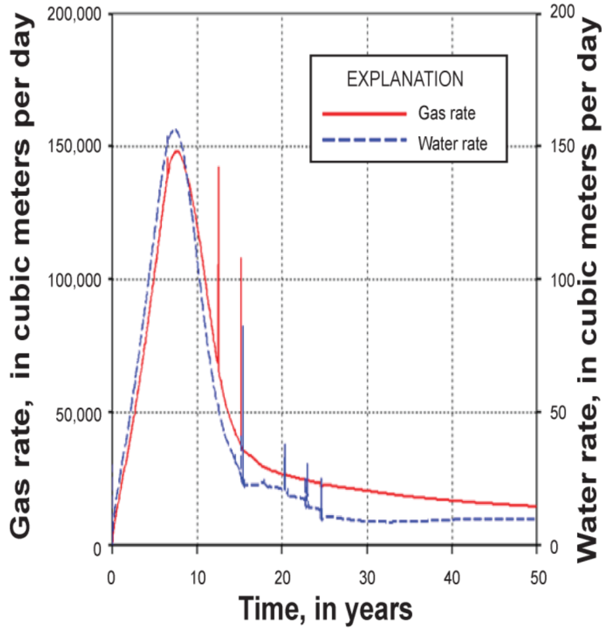
L-Pad vicinity (5-6 °C)

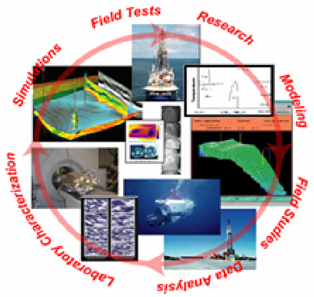
>20,000 m^3/day



PBU Down-dip (10-12 °C)

>150,000 m^3/day





Modified from Anderson et al., 2011

Alaska North Slope

Extended Gas Hydrate Production Testing – PBU Site Review

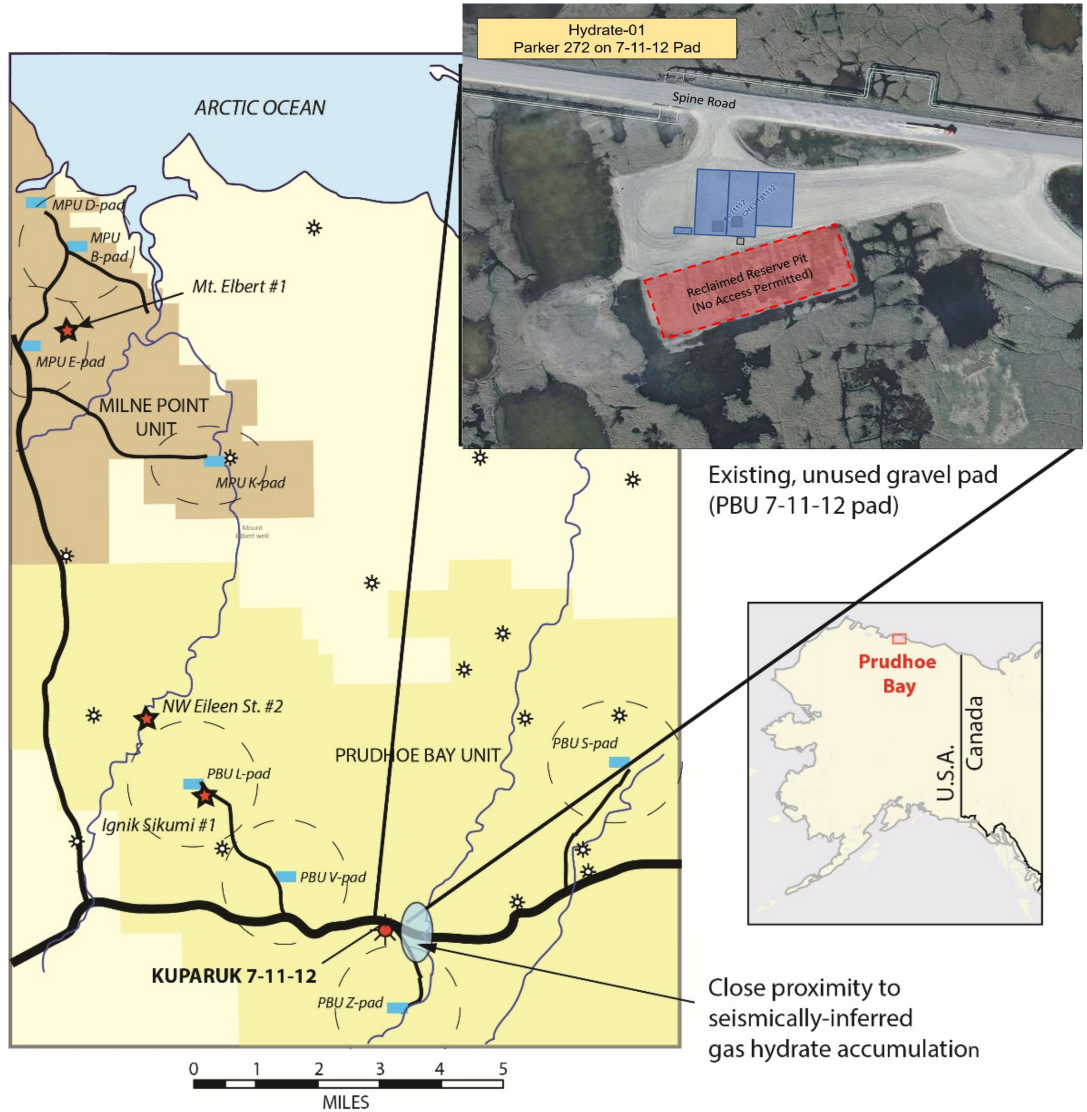
- Conduct a long-term test of gas hydrate response to most favorable production technology.

- Leverage known gas hydrate occurrences on the Alaska North Slope that are co-located with required infrastructure (pads, roads, services, EHS).

- Negotiate viable operating structure with ANS industry who are currently unwilling to engage as R&D partners.

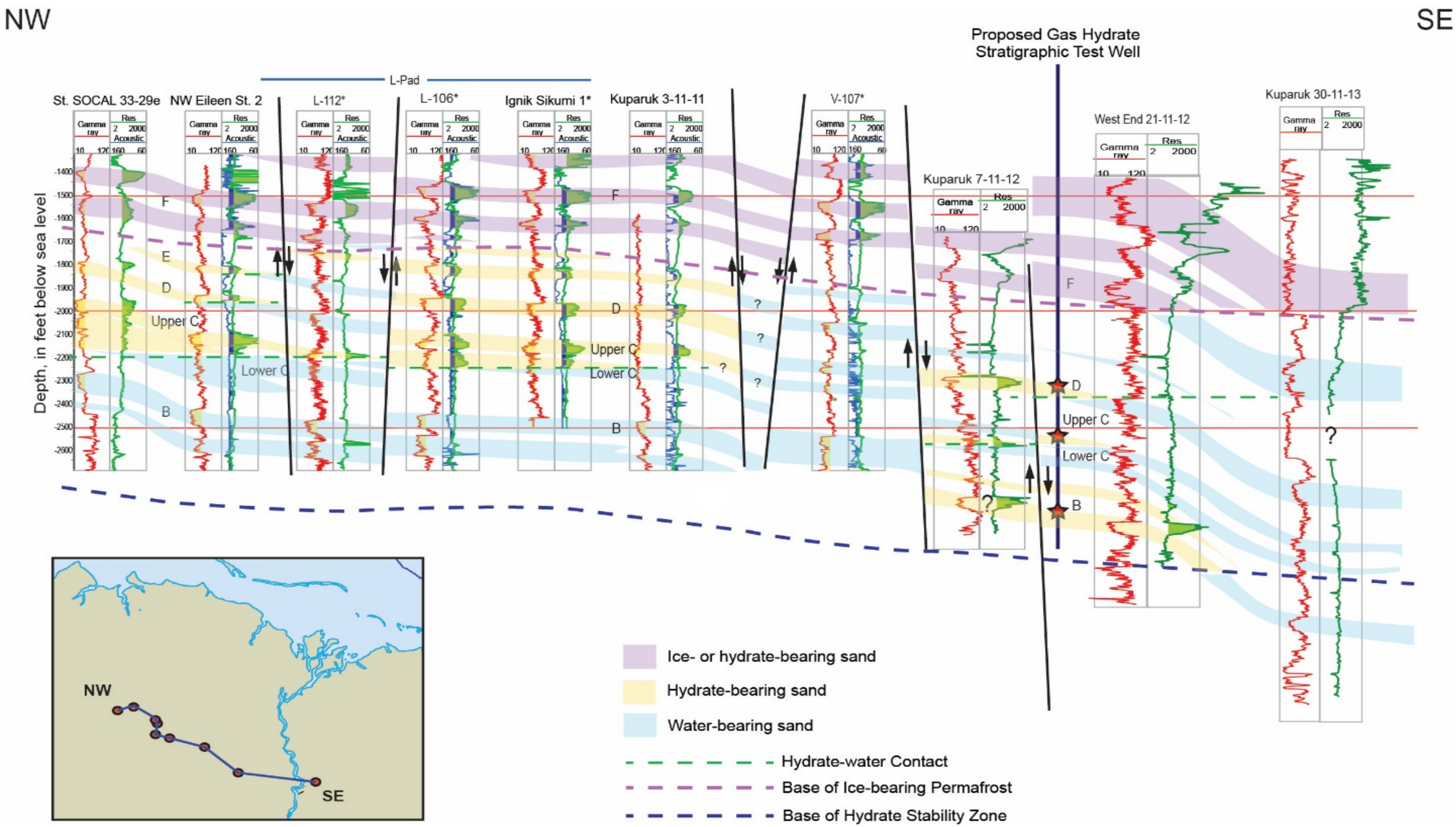
- Address common goals as specified in agreements with Alaska Department of Natural Resources and the Government of Japan.

- **Completed initial drilling to confirm a promising site identified in the Westend Prudhoe Bay Unit.**



Eileen Gas Hydrate Accumulation

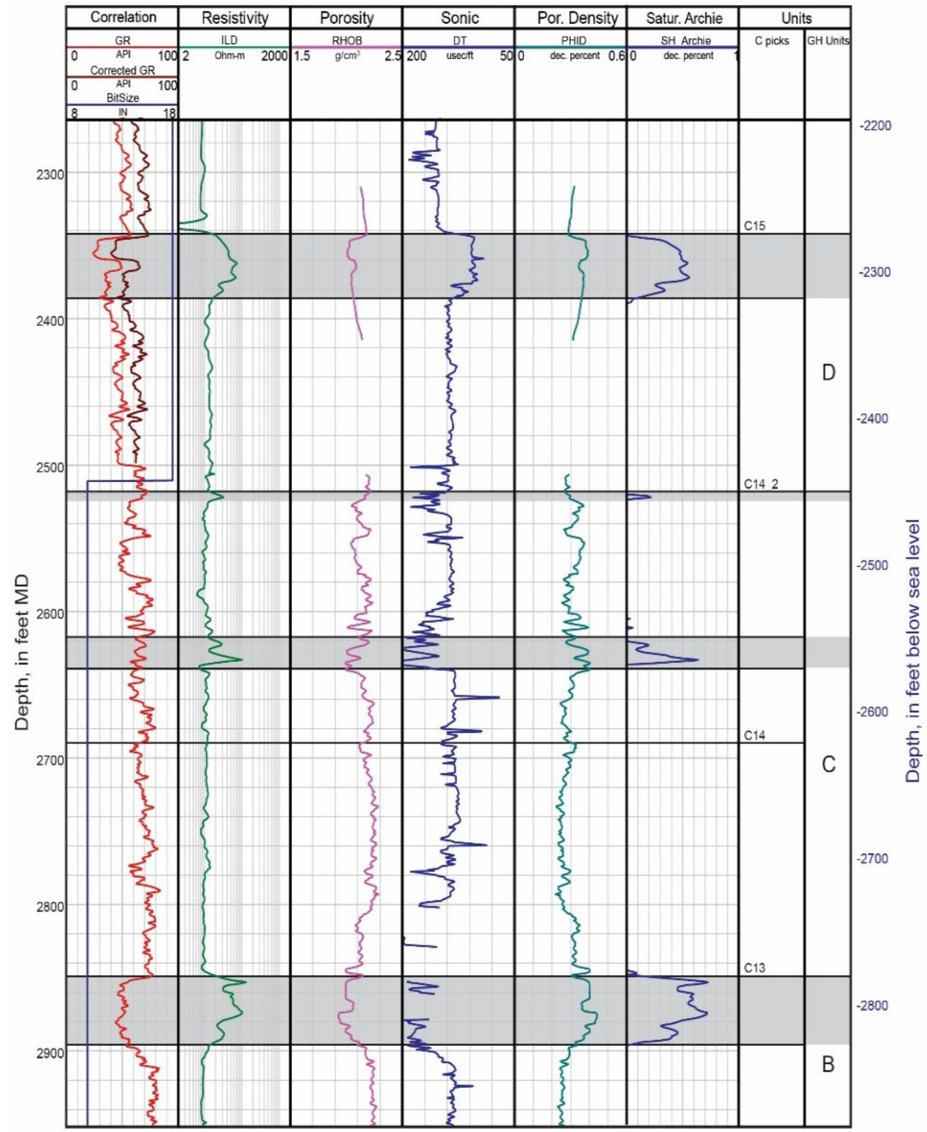
Westend PBU Well log Correlation Section



Modified from Boswell et al., 2016

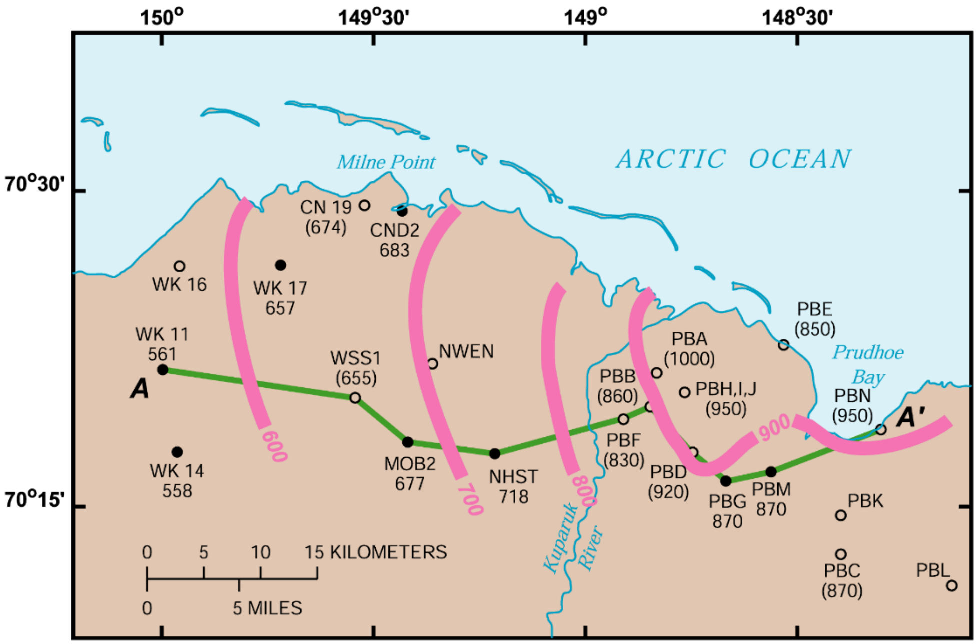
PBU 7-11-12 Gas Hydrate Occurrences
Well Log Derived Porosities and GH Saturations

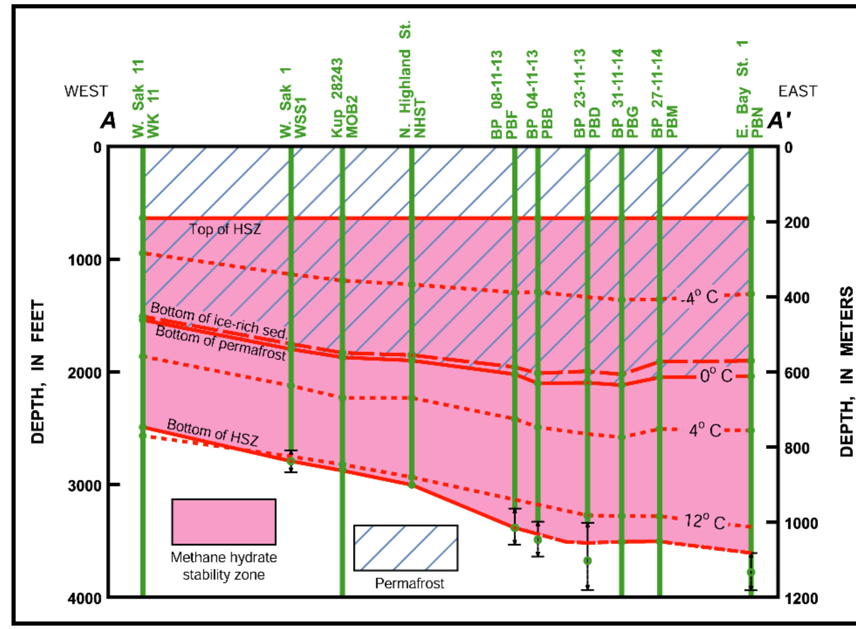
- Two older exploration wells from the Mobile 7-11-12 gravel pad
- Unit D: GH likely (low geologic risk)
- Unit C: Evidence of limited inferred GH occurrence
- Unit B: Possible GH or FG occurrence, poor log quality
- Drilling-disturbance at time of logging at the Unit B level
- Unit B predicted to occur ~100’ above BGHS
- DNR-WIOs enabled seismic review suggests opportunity to the east (D & B); but unclear ties, phase behavior, and structure

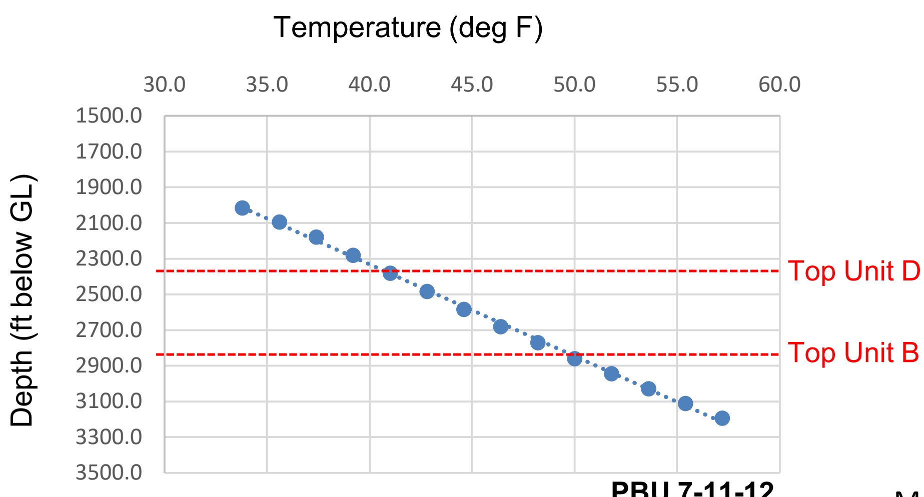


Greater PBU Area GH Stability Conditions

PBU 7-11-12 Temperature Profile







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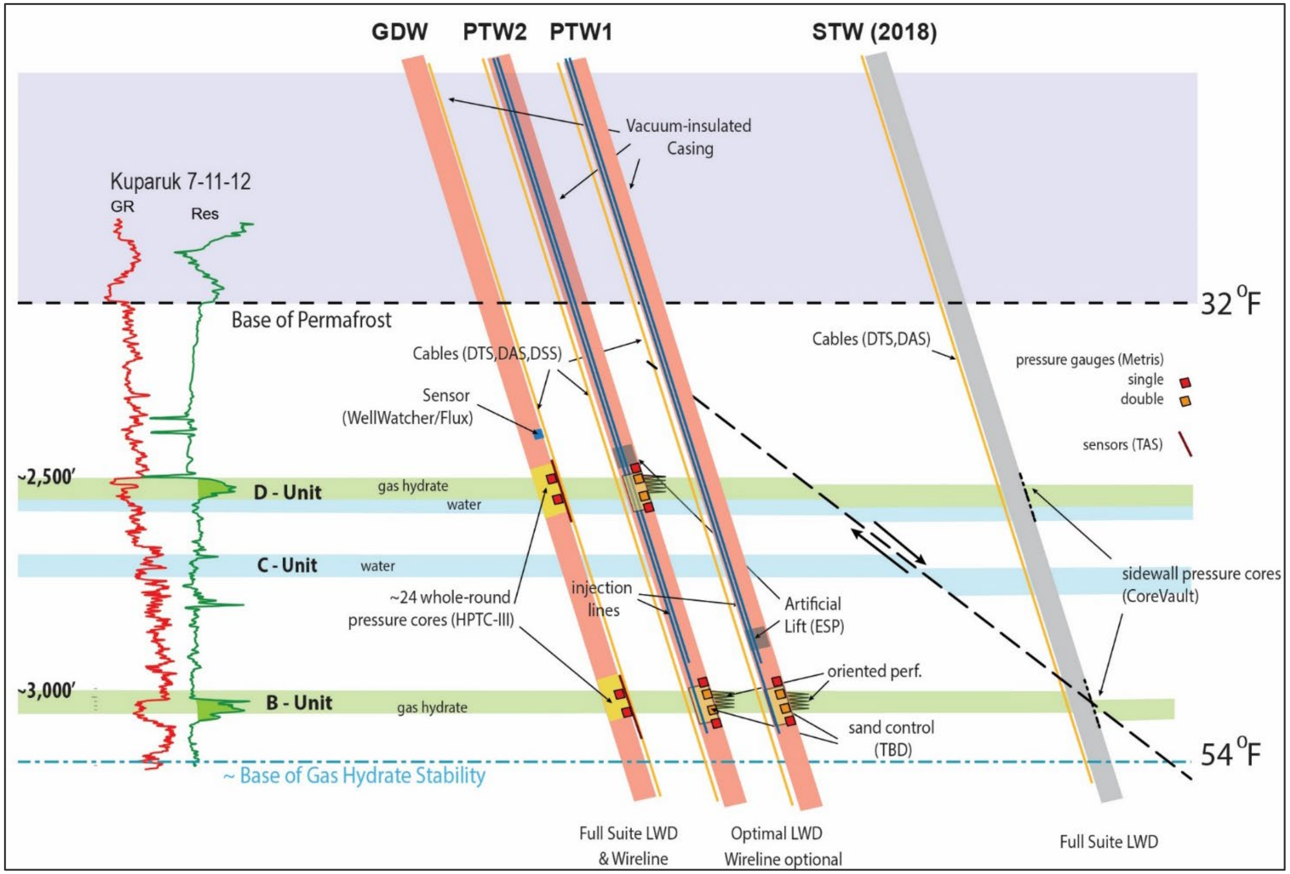
Modified from Collett et al., 2015

Alaska Gas Hydrate Production Field Experiment
Extended Gas Hydrate Production Testing

Alaska Gas Hydrate R&D

- Cooperative effort to gather necessary G&G and conduct monitored depressurization test
- DOE, JOGMEC, and USGS identified and evaluated potential test sites and designing four well testing program
- Completed Hydrate-01 Stratigraphic Test Well in December 2018
- Drilling of GDW/PTWs around 3Q/4Q 2021, followed by around 1-year long production test that could be longer



Alaska Gas Hydrate Production Field Experiment

Extended Gas Hydrate Production Testing

Project Goal

The primary goal of this project is to conduct a scientific field production test of one or more gas hydrate bearing sand reservoirs using conventional "depressurization" technology. The project will include the drilling and evaluation of a stratigraphic test well (*completed in December 2018*), followed by the establishment of a production test site (*including surface monitoring, instrumented monitoring wells, and two production test wells; to be completed in December 2021*), and then the testing of reservoir response to pressure reduction over a period from 12 to 24 months.

Project Organization Chart

Steering Committee

Brian Anderson (Director, NETL)
Timothy Reinhardt (Director of Supply and Delivery, Office of Fossil Energy, DOE)
Toshikazu Ebato (Executive Vice President, JOGMEC)
Koji Yamamoto (Group Leader of Methane Hydrate R&D Group, JOGMEC)

Authorize implementation plan at each stage gate.

Administration Coordinator

Contract formulation and execution and budget expenditure.
Nori Okinaka (JOGMEC)
Don Hafer (NETL)

R&D Committee

Science/technology implementation plan.
Nori Okinaka (JOGMEC)
Ray Boswell (NETL)
Tim Collett (USGS)
Osamu Matsubara (JOGMEC)
Yoshihiro Nakatsuka (JOGMEC)
Naoyuki Shimoda (JOGMEC)
Mizuki Sato (JOGMEC)
Many other per Topic

Site Representatives

Real-time decision-making during field programs.
Ray Boswell (NETL), Tim Collett (USGS), Scott Marsteller (NETL)
Nori Okinaka, Motoi Wakatsuki (JOGMEC)

Decision Making Mechanism

Alaska Gas Hydrate Production Field Experiment

Project Operational and Science Planning

PROPOSED DOE-JOGMEC-USGS GAS HYDRATE FIELD TESTING PROJECT

OVERVIEW OF PROJECT OBJECTIVES AND DRAFT FIELD OPERATIONS PLAN
FOR THE KUPARUK 7-11-12 SITE, PRUDHOE BAY UNIT, ALASKA NORTH SLOPE

Draft Document for Purpose of Discussing Potential Partnership with the Prudhoe Bay Unit Working Interest Owners

Prepared by
US DOE/NETL
JOGMEC
US Geological Survey

DRAFT

Alaska Gas Hydrate Production Field Experiment: GDW and PTWs Science and Operation Plan

DRAFT

September 12, 2020

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U.S. DEPARTMENT OF ENERGY

bp
BP Exploration Alaska Inc.

Hydrate-01 Well Operations Program

Parker 272

Methane Hydrate Stratigraphic Test Well

Statement of Requirements (SoR)
Rotary Rig Candidates

WELL NAME	Updated By	Date	Summary of Update
HydrateTest 1			

(1) General Information

Prospect name	HydrateTest 1
Target Horizon - Primary	Unit B
Target Horizon - Secondary	Unit D
Well Classification:	Stratigraphic
Field / Area:	PBU / ANS

	NAD27 State Plane Zone 4		Section / Township / Range	From the south line	From the
Surface location	X = 598695.0	Y = 5966140.0	7 / 11N / 12E		
Kick off Point	300		7 / 11N / 12E		
Target location top of (Sagavanirktok) Unit B (2,770 TVDss)	X = 599368.32	Y = 5966414.04	7 / 11N / 12E		
Bottom Hole location	X = 599494.56	Y = 5966465.52	7 / 11N / 12E	TBD	TB
MD Planned	3502				
TVDss Planned	3280				
Vertical Section	863				

Well Type:	Stratigraphic Test, New Well, Deviated
Any wells required to be shut-in?	No
Drilling through hydrates or free gas?	Yes
Drilling through shallow disposal zones?	No
Drilling through shallower active reservoirs?	No
Drilling through depleted or over-pressure zones?	No
Additional pressure or surveillance data required?	No

(2) Cost Information

Estimate TBD with Drilling Service Agreement

D&C Time Estimate (Days)	TBD
Pre-Rig Ops Cost Estimate	TBD
D&C Cost Estimate	TBD
Post-Rig Testing Cost Est.	TBD
Total Cost	TBD

(3) Specific Well Objectives and Define Success

In Order of Priority

Objective: Confirm the presence, temperature, thickness, reservoir saturation, and grain size (CoreVault) of gas hydr

bp
JOGMEC
USGS
PRA

Prudhoe Bay

Hydrate-01

Wireline Logging Program
8.5" Section

MI SWACO
bp

DRILLING AND COMPLETION FLUIDS PROPOSAL

BP ALASKA
HYDRATE -01
Two Interval Grassroots
Gas Hydrate Stratigraphic Test well

Parker rig 272

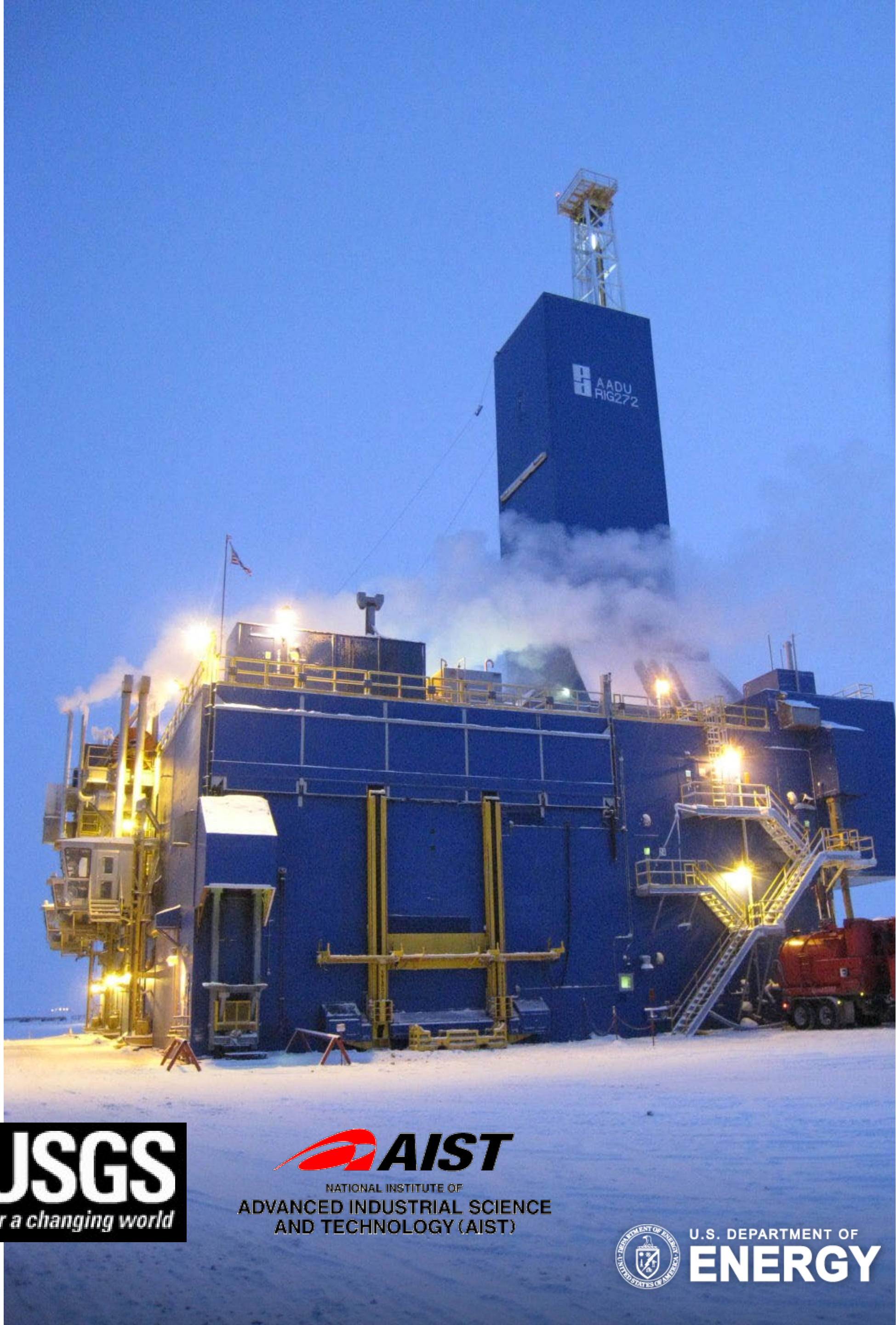
bp
JOGMEC
USGS
PRA

Hydrate-01

MWD/LWD Data Acquisition Program

Alaska Gas Hydrate Production Field Experiment

Hydrate-01 Stratigraphic Test Well Operations and Technical Results



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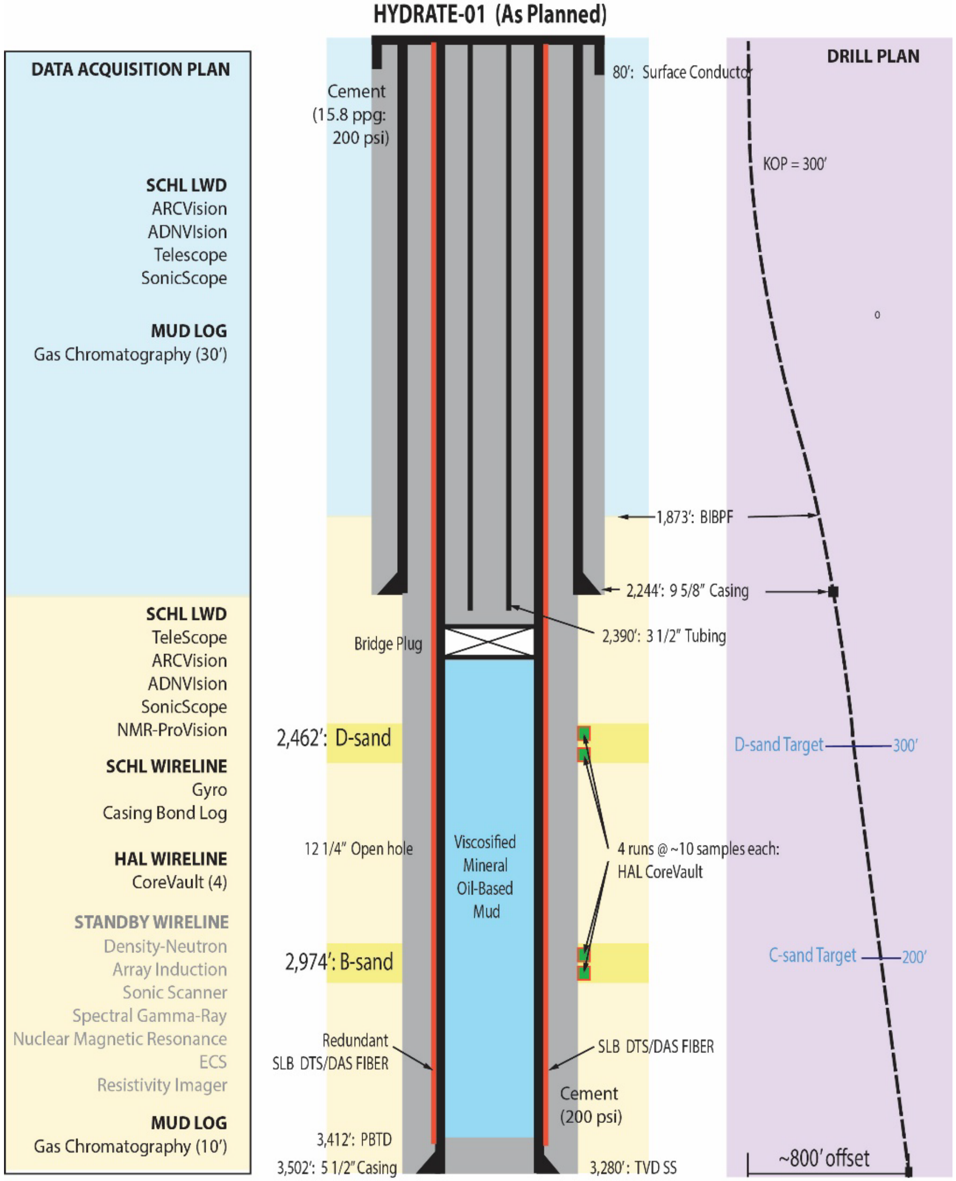
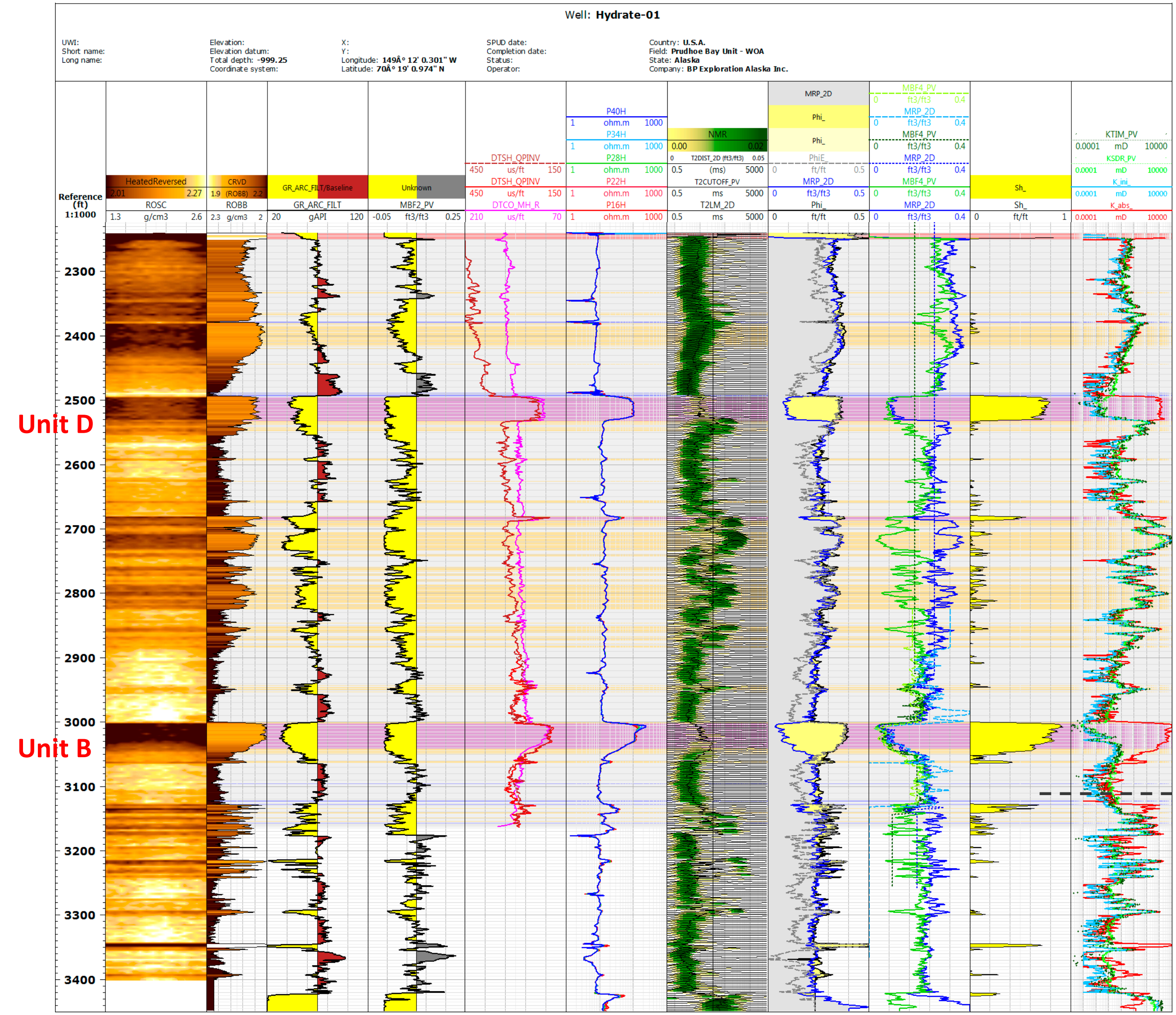
U.S. DEPARTMENT OF ENERGY

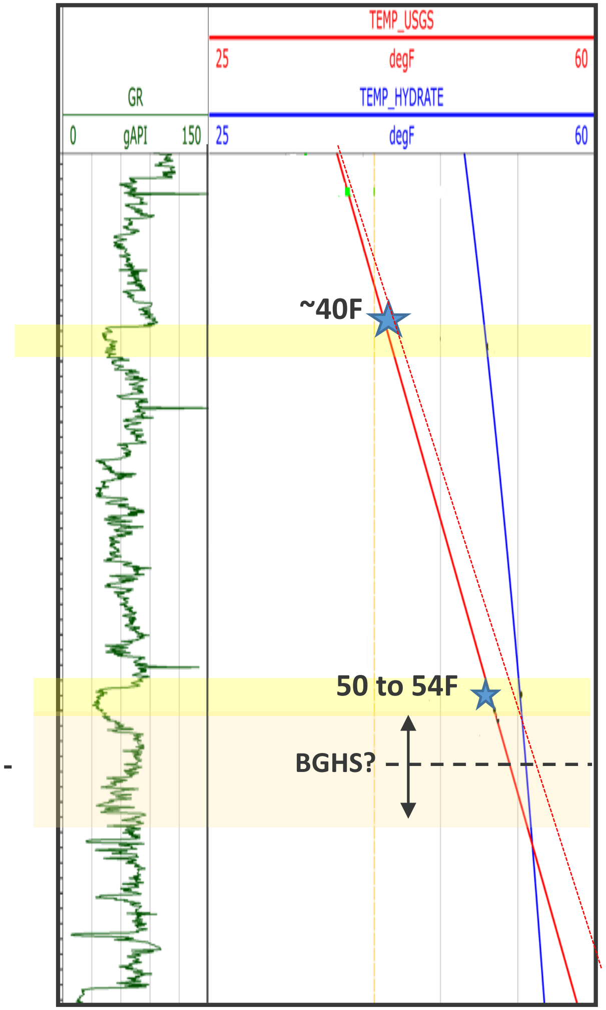
PBU Hydrate-01 Stratigraphic Test Well
Well Design and Operations

- BPXA gained partner alignment to operate STW (warm up of rig for the impending PBU 2019 drilling season)
- Program was designed to acquire ONLY essential data
  - Full logging suite to confirm reservoir occurrence and characteristic
  - Side wall pressure cores to provide data to support planning of test well completion
  - Installed FO cables to allow STW to support VSP and serve as a monitoring well for future operations



PBU Hydrate-01 Stratigraphic Test Well





Modified from Boswell et al., 2020 - ICGH10

PBU Hydrate-01 Stratigraphic Test Well

Well Logging and Sidewall Pressure Coring

BHA	LWD Log Run	Hole Section	Comments	Date Started	Date Finished	MWD Top (ft MD)	MWD Bottom (ft MD)	MAD Top (ft MD)	MAD Bottom (ft MD)	LWD and MWD Tools Primary Measurements
1		12.25 in	No data							
2	LWD001	12.25 in	Drill to casing point	11-Dec-18	13-Dec-18	318.25	2205	100	318.25	arcVISION 825 (gamma ray, resistivity) TeleScope 825 MWD (survey-power-com) SonicScope 825 (acoustic velocity) SadnVISION (neutron-density porosity)
3		12.25 in	No data: Clean Out							
4	LWD002	8.5 in	No data: Remove RSS							
5	LWD003	8.5 in	Drill to core point	20-Dec-18	23-Dec-18	2205	3224	2229.75	3256.83	arcVISION 675 (gamma ray, resistivity) TeleScope 675 MWD (survey-power-com) SonicScope 675 (acoustic velocity) proVISION 675 (NMR) adnVISION (neutron-density porosity)
6	LWD004	8.5 in	Drill to TD	25-Dec-18	26-Dec-18	3224	3522	2726	3160	arcVISION 675 (gamma ray, resistivity) TeleScope 675 MWD (survey-power-com) SonicScope 675 (acoustic velocity) proVISION 675 (NMR) adnVISION (neutron-density porosity)

Logging-while-drilling (LWD) and measurement-while-drilling (MWD) program as completed in the Hydrate-01 Stratigraphic Test Well

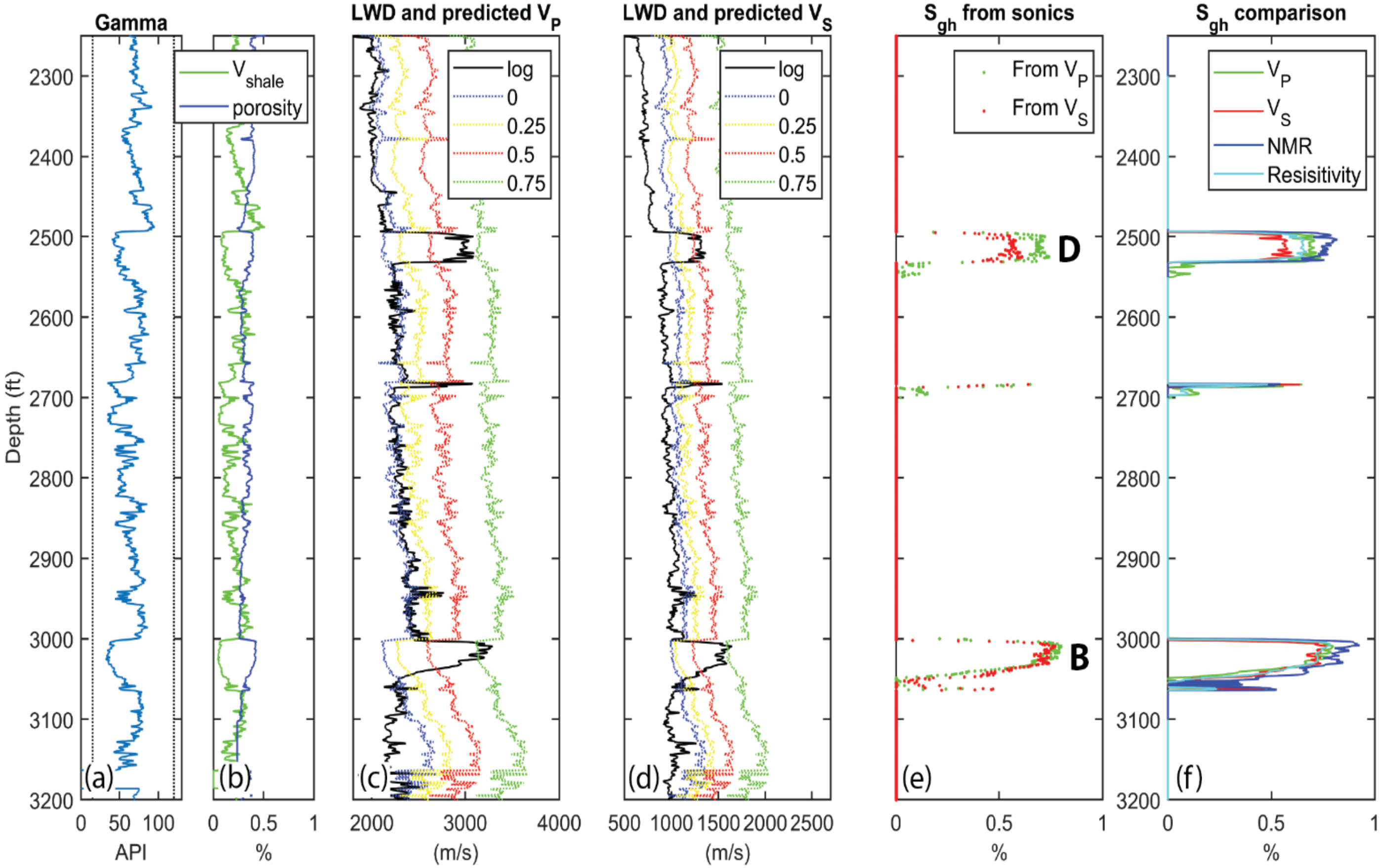
Core Run and Core Number	Core Depth (ft MD)	BP Sample ID	BP Sample Depth (ft MD)	Stratigraphic Unit	Assigned Laboratory
1 - 2	3,006.01	1-2	3,006.00	Unit B	Weatherford
1 - 3	3,007.04	1-3	3,007.00	Unit B	Weatherford
1 - 4	3,008.05	1-4	3,008.00	Unit B	Weatherford
1 - 5	3,009.05	1-5	3,009.00	Unit B	Weatherford
1 - 6	3,011.02	1-6	3,011.00	Unit B	Weatherford
1 - 7	3,013.08	1-7	3,013.00	Unit B	Weatherford
1 - 8	3,015.01	1-8	3,015.00	Unit B	Weatherford
1 - 10	3,019.02	1-10	3,019.00	Unit B	Weatherford
1 - 12	3,023.05	1-12	3,025.00	Unit B	Weatherford
1 - 13	3,026.03	1-13	3,027.00	Unit B	Weatherford
2 - 1	3,032.00	2-18	3,032.00	Unit B	Weatherford
2 - 2	3,033.01	2-19	3,033.00	Unit B	Weatherford
2 - 3	3,035.05	2-20	3,035.00	Unit B	AIST
3 - 1	2,498.02	3-22	2,498.00	Unit D	AIST
3 - 2	2,501.07	3-23	2,501.00	Unit D	AIST
3 - 3	2,501.07	3-24	2,504.00	Unit D	Weatherford
3 - 4	2,504.15	3-25	2,507.00	Unit D	AIST
3 - 5	2,511.04	3-27	2,511.00	Unit D	AIST
3 - 6	2,513.05	3-28	2,513.00	Unit D	Weatherford
3 - 7	2,516.07	3-29	2,516.00	Unit D	AIST
3 - 8	2,519.03	3-30	2,519.00	Unit D	AIST
3 - 9	2,522.06	3-31	2,522.00	Unit D	Weatherford
3 - 10	2,525.10	3-32	2,525.00	Unit D	AIST
4 - 1	3,010.04	4-33	3,010.00	Unit B	AIST
4 - 2	3,014.09	4-34	3,014.00	Unit B	Weatherford
4 - 3	3,016.04	4-35	3,016.00	Unit B	AIST
4 - 4	3,018.04	4-36	3,018.00	Unit B	AIST
4 - 5	3,024.02	4-38	3,024.00	Unit B	AIST
4 - 6	3,040.01	4-39	3,040.00	Unit B	AIST
5 - 1	3,078.07	5-44	3,078.00	Lower Seal	Weatherford
5 - 2	3,074.03	5-45	3,074.00	Lower Seal	Weatherford
5 - 3	3,070.02	5-46	3,070.00	Lower Seal	Weatherford
5 - 4	Unknown	Unknown	Unknown	Lower Seal	Weatherford
5 - 5	Unknown	Unknown	Unknown	Lower Seal	Weatherford

Listing of sidewall pressure cores recovered in the Hydrate-01 Stratigraphic Test Well using the Halliburton CoreVault system

Modified from Collett et al., 2020 - ICGH10

PBU Hydrate-01 Stratigraphic Test Well

Well Log Analysis



Gas hydrate saturations (S_{gh}) from sonic and other log data.

a. Gamma ray log data

b. LWD derived shale volume (V_{sh}) and porosity logs

c. LWD-measured V_P (black line) and model predicted V_P for S_{gh} values

d. LWD-measured V_S (black line) and model predicted V_s for S_{gh} values

e. Predicted V_S and V_P Gas hydrate saturations (S_{gh})

f. Comparison of S_{gh} estimated from V_P and V_S, NMR-DEN porosity, and resistivity LWD-measurements

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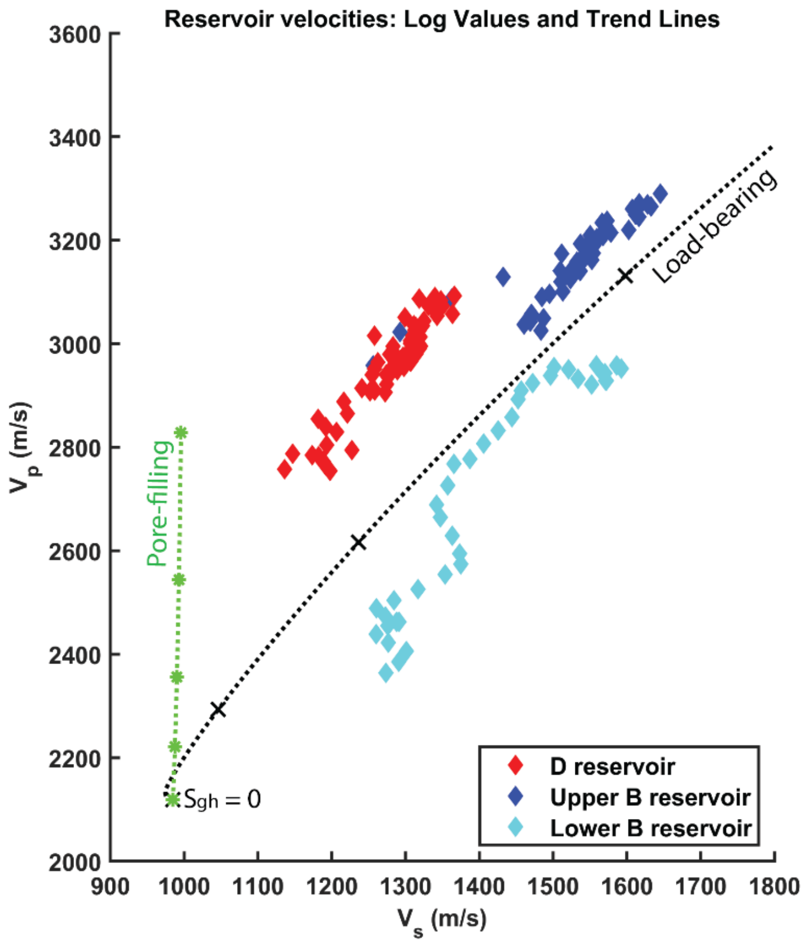
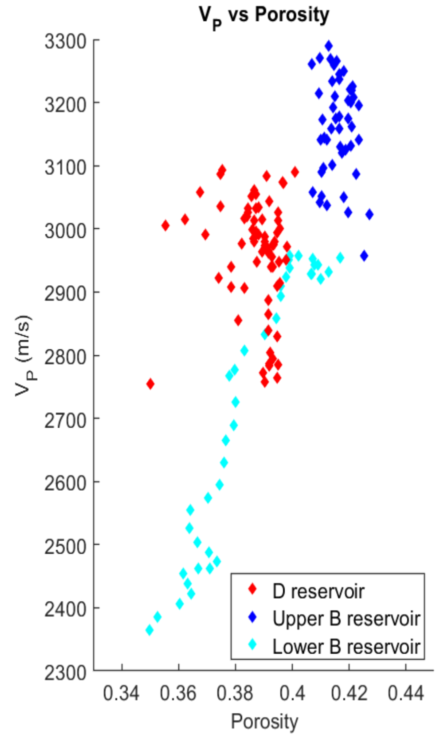
Haines et al., 2020 - ICGH10

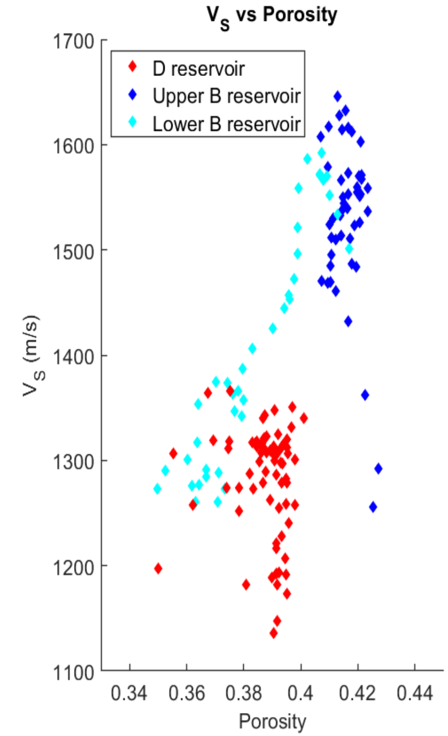
PBU Hydrate-01 Stratigraphic Test Well

Well Log Analysis



On a crossplot of the V_P / V_S LWD derived log data points from the hydrate-bearing reservoir units (Units B and D) in the Hydrate-01 plot around the model derived "load-bearing" trend line; which suggest that the gas hydrate may act as part of the reservoir rock matrix.





The crossplot of V_P and V_S LWD derived log data points from sonic logs versus density log derived porosity values for the primary reservoir units in the Hydrate-01 well exhibit increasing V_P and V_S log values with increasing porosity, which is a product of the high acoustic velocity nature of gas hydrate.

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Haines et al., 2020 - ICGH10

PBU Hydrate-01 Stratigraphic Test Well
DAS 3D VSP Geophysical Acquisition

March 3-15, 2019: Largest known 3D DAS VSP acquisition

- Utilizing FO DAS cables installed in STW
- Goal is to confirm local structure/phase distribution to refine placement of GDW and PTW
- Provide baseline for potential future 3D VSPs during and/or after testing
- Despite weather challenges - acquired 1,701 of 1,740 (98%) planned shot points

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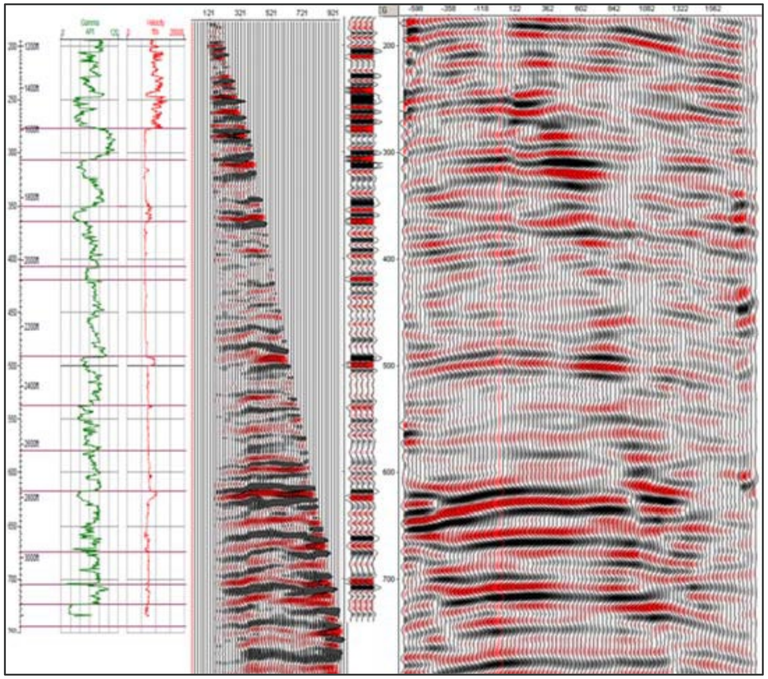
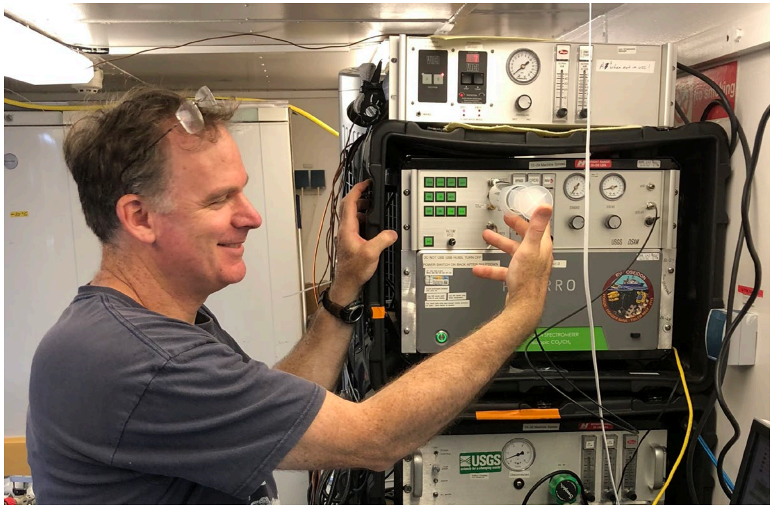


Modified from Lim et al., 2020 - ICGH10

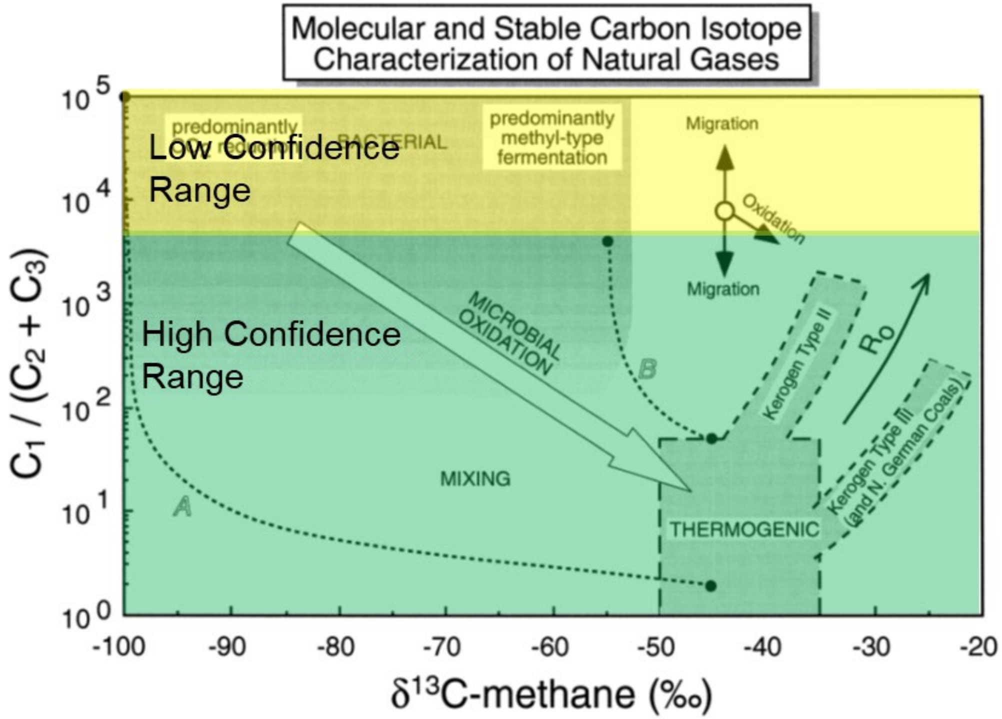
PBU Hydrate-01 Stratigraphic Test Well

Gas Hydrate System Analysis – Gas Geochemistry



Picarro G2210-*i*-AM1 CRDS interfaced to USGS Discrete Sample Introduction Module (DSIM)

Analyzer: Measures C_1/C_2 and $\delta^{13}CH_4$
DSIM: Quantitative dilution
System: Field Ready



~90% of data from the global 20,000+ Milkov & Etiope (2018) database are in the high confidence region

Real Time Gas Compositional and Isotopic Data

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Hydrate-01 Data Acquisition – Results

Drilling/wellbore quality (to allow reliable data collection)

- FULLY ACHIEVED: both targets penetrated within provided target. Mud temperature maintained within set limits (as modified). No incidents of induced GH dissociation; hole in gauge.

Logging-while-drilling (data to confirm/characterize reservoir condition)

- FULLY ACHIEVED: outstanding quality data with all tools!
- **NOTE**: Sonic data – muted reservoir response in lower portion of B target. Verified proper tool response through two additional MAD passes across the reservoir.

Contingency Wireline data

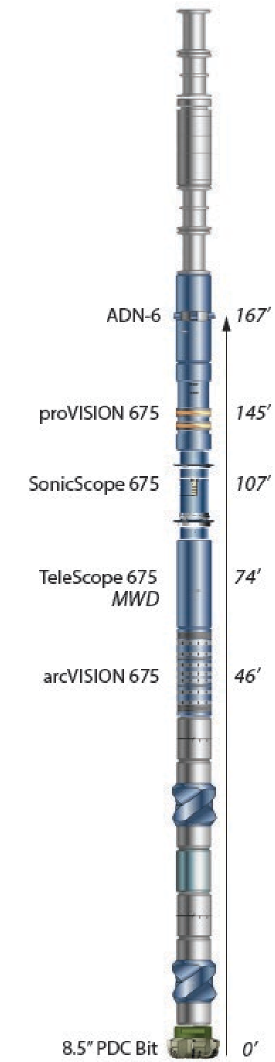
- DEFERRED PER PLAN: Not required due to high quality of LWD data.

Sidewall pressure cores (grain size analyses & test well completion design)

- FULLY ACHIEVED: 39 samples recovered spanning full extent of both reservoirs.
- **NOTE**: Obtained additional petrophysical data from the highest quality cores.

Fiber Optic cable installation (to enable use of STW as monitoring well)

- FULLY ACHIEVED: Two (one as backup) distributed temperature/acoustic sensor cable packages were installed on outside of casing and successfully tested.



Bottom-hole assembly for main hole (from Schlumberger)

PBU Hydrate-01 Stratigraphic Test Well

2018 STRATIGRAPHIC TEST WELL PROGRAM

10th International Conference on Gas Hydrates (ICGH10)

Scheduled for July 18-23, 2021 in Singapore

https://www.netl.doe.gov/node/10037

- Progress toward the establishment of an extended-duration gas hydrate reservoir response test on the Alaska North Slope
  Norihiro Okinaka, Japan Oil, Gas and Metals National Corporation (JOGMEC, a member of MH21-S R&D consortium), Japan, et al.
- Alaska North Slope 2018 Hydrate-01 Stratigraphic Test Well: Technical Results
  Ray Boswell, National Energy Technology Laboratory, USA, et al.
- Design and Operations of the Hydrate 01 Stratigraphic Test Well, Alaska North Slope
  Timothy S. Collett, U.S. Geological Survey, USA, et al.
- Numerical Simulations of Gas Production from Gas Hydrate Reservoirs at the Prudhoe Bay Unit 7-11-12 Pad on Alaska North Slope
  Evgeniy Myshakin, Leidos Research Support Team, National Energy Technology Laboratory, USA, et al.
- Petrophysical and geomechanical properties of gas hydrate-bearing sediments recovered from Alaska North Slope 2018 Hydrate-01 Stratigraphic Test Well
  Jun Yoneda, National Institute of Advanced Industrial Science and Technology (AIST), Japan, et al.
- DAS-3DVSP Data Acquisition at 2018 Hydrate-01 Stratigraphic Test Well
  Teck Kean Lim, Toyo Engineering Corporation, Japan, et al.
- Gas hydrate saturation estimation from acoustic log data in the 2018 Alaska North Slope Hydrate-01 stratigraphic test well
  Seth S. Haines, U.S. Geological Survey, USA, et al.
- Fully Thermal-Hydro-Chemo-Mechanical (THCM) Coupled Numerical Simulations of Gas Production from Gas Hydrate Reservoirs at Alaska North Slope
  Xuerui Gai, National Energy Technology Laboratory, USA, et al.
- Numerical modeling of sand migration during gas production from gas hydrate reservoir in the Prudhoe Bay Unit on the Alaska North Slope
  Shun Uchida, Rensselaer Polytechnic Institute, USA, et al.

Alaska Gas Hydrate Production Field Experiment

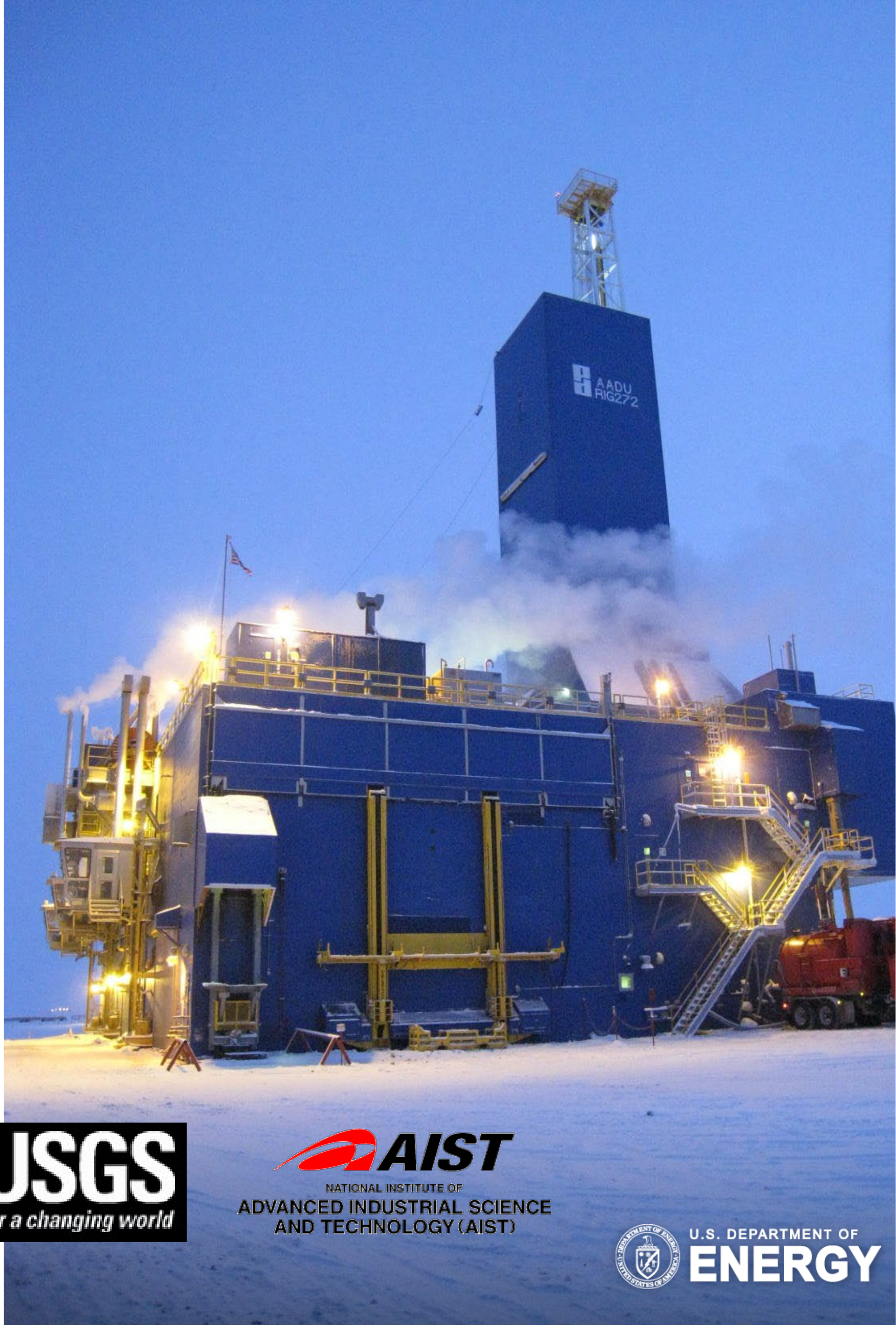
Project Status

- Based on the Hydrate-01 STW, hydrate occurrence in Units B and D confirmed by R&D Committee (RDC) in Feb, 2019
- Steering Committee (SC) endorsed plan to develop detailed implementation plan for a long-term production test, and to select Third Party Operator (TPO) in May, 2019
- Analysis of data acquired from STW and associated 3D VSP – continuing
- Acquisition of DTS data from STW
- Acquiring elevation survey data

Hydrate-01
Wellhead

Alaska Gas Hydrate Production Field Experiment

Operations and Science Planning



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

U.S. DEPARTMENT OF ENERGY

Plans for Future Testing

Alaska Gas Hydrate Production Field Experiment: GDW/PWTs Science and Operational Plan

1. Well Delivery: Engineering Planning and Operations

2. PTWs Completion and Production Testing Program

- -PTWs Completions
- -Surface Facilities
- -Production Testing Planning and Design
- -Testing Operations
- -Measurement of Well Responses: Produced fluid/Gas Volumes, P/T Responses with Surface & Down Hole Equipment
- -Testing Results Analysis (Pre-Test Production Modeling and Post-Testing Code Calibration Efforts)

3. Well-Based Data Acquisition and Analysis

- -Introduction of the GDW, PTW-1, PTW-2 Data Acquisition
- -Mud Logging Program
- -Downhole LWD/Wireline Logging Program
- -Pressure Coring System & Operations
- -Coring Plan
- -Well Site Core Flow and Analysis
- -Post Well Site Core Shipping, Processing and Analysis

4. GDW and PTWs Monitoring Program

- -DTS/DAS/DSS and Gauge Based P&T Systems and Surface Monitoring Systems
  - Introduction to the Monitoring Program
  - GDW-PTWs Distributed Systems - DTS/DAS/DSS – Technology Review
  - GDW and PTWs Pressure and Temperature Gauges – Technology Review
  - GDW – Temperature Array Sensors (TAS), P/T Gauges, DTS/DAS/DSS
  - PTWs – P/T Gauges, DTS/DAS/DSS
  - Surface Monitoring Systems Surface – Elevation Surveys
- -4D VSP/CWT Geophysical Data Acquisition: Test Site Characterization and Production Monitoring

Geologic Data Well (GDW) and Production Test Wells (PTWs) Data Acquisition

- **GDW LWD Surface Hole:** Drilling (MWD) parameters, GR, RES, SONIC, directional drilling
- **GDW LWD Main Hole:** Drilling (MWD) parameters, GR, RES, SONIC, NMR, directional drilling
- **GDW WLL Main Hole:** GR, RES, SONIC, NMR, borehole scanning, geochemical logging
- **GDW:** Accessible for production logging: Directional Gyro, cement evaluation
- **GDW:** Pressure-coring (HPTC) Units C and D reservoir and bounding units, with PCATS
- **GDW-PTW Mud-logging:** Industry contract with cuttings and gas samples
- **PTWs LWD Surface Hole:** Simplified program (Drilling MWD parameters & GR) to maximize hole quality (assuming primary data acquisition in GDW)
- **PTWs LWD Main Hole:** Same as GDW, with WLL contingent on data quality in GDW
- **PTWs:** Accessible for production logging: Directional Gyro, cement evaluation
- **GDW Monitoring:** DTS-DAS-DSS, temperature and pressure gauges behind casing
- **PTWs Monitoring:** DTS-DAS-DSS, temperature and pressure gauges behind casing
- **PTWs Monitoring:** Fluids (gas and produced formation water) volumes and rates, produced solids, and gas/water chemistry real time and samples, etc.

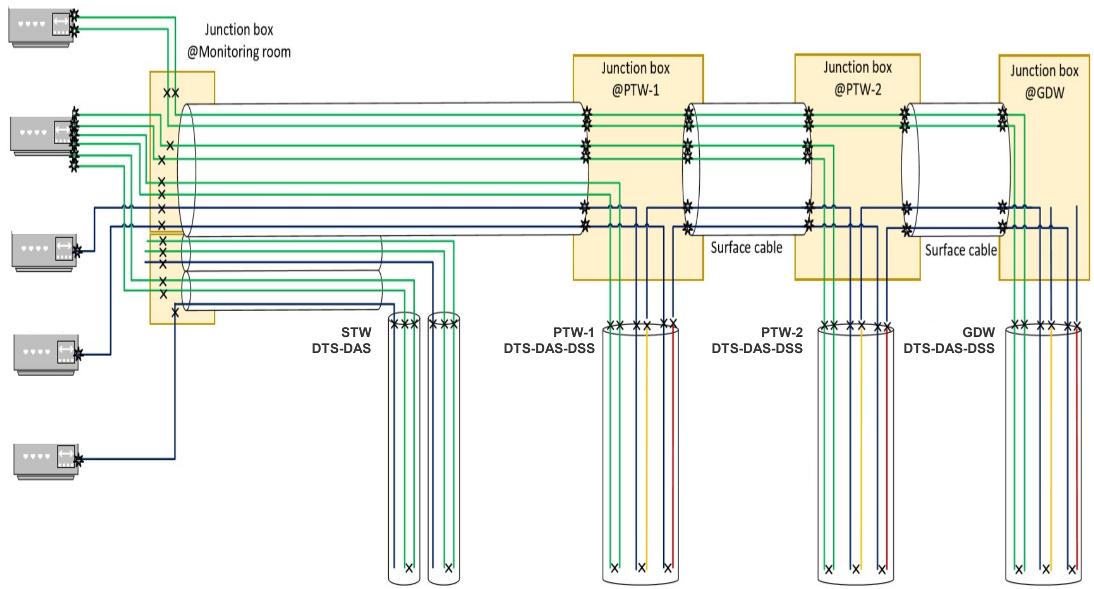
Production Test Well Monitoring
Distributed and Gauge Based Systems

TYPES OF DISTRIBUTED SENSING

Distributed Temperature Sensing (DTS) is the most widely used form of distributed sensing. It can precisely measure temperatures up to 300°C (570°F) every meter along the fiber to an accuracy of +/- 1°C (1.8°F) and a resolution to +/- 0.01°C (0.018°F).

Distributed Acoustic Sensing (DAS) effectively turns the fiber cable into a series of geophones (or microphones) to identify near wellbore injection and production, cross well monitoring, fluid densities, fluid migration, and casing leaks, and/or for early detection of equipment wear or failure. In addition, DAS is a cost-effective alternative to traditional vertical seismic profiles (VSPs). DAS offers thousands of sensor points and repeatable time-lapse imaging.

Distributed Strain Sensing (DSS) can help to determine casing deformation location and severity, or provide insight into stresses produced at perforations during stimulation.



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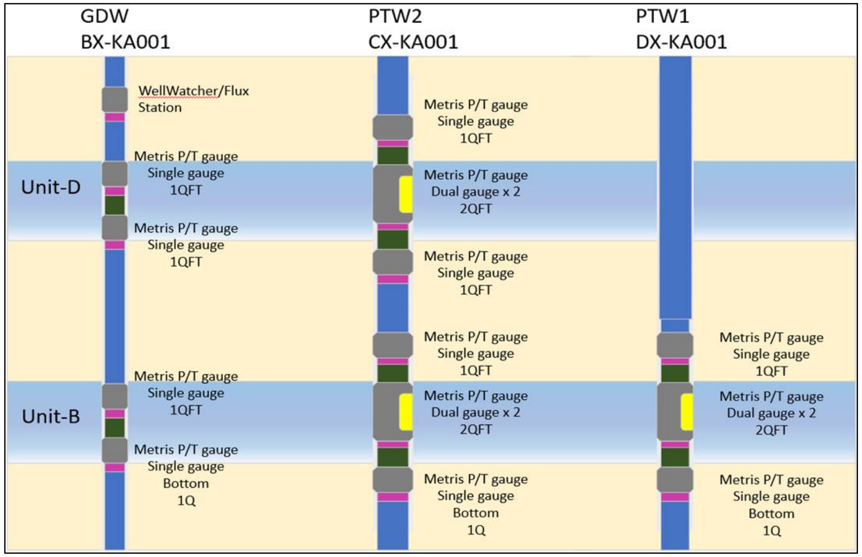
TOYO ENGINEERING



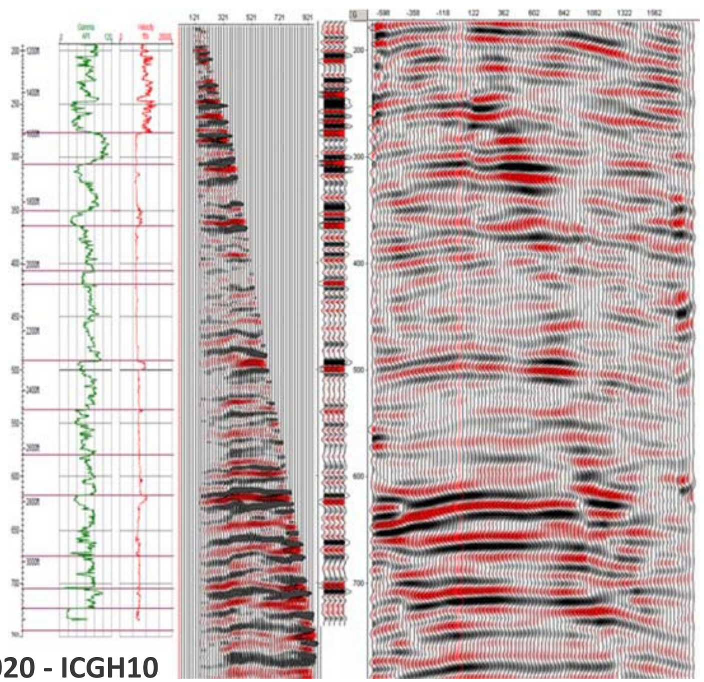
Gauge Systems
1Q = Single Port P/T gauge (formation)
2Q = Double Port P/T gauge (formation/tubing)
FT = Cable feed-through

Production Test Well Monitoring
DAS *4D VSP Geophysical Monitoring*

Monitoring reservoir changes during the production test

- Time-lapse DAS VSP data
  - Acquire surveys before and after production test (possibly also during)
  - Observe changes in seismic response
  - Characterize and quantify reservoir conditions using rock physics relationships

- Collaboration with CSM to support this work
  - Developing numerical models for survey planning and algorithm development
  - Reprocessing 2019 3D DAS VSP data
  - Preparing for time-lapse data availability

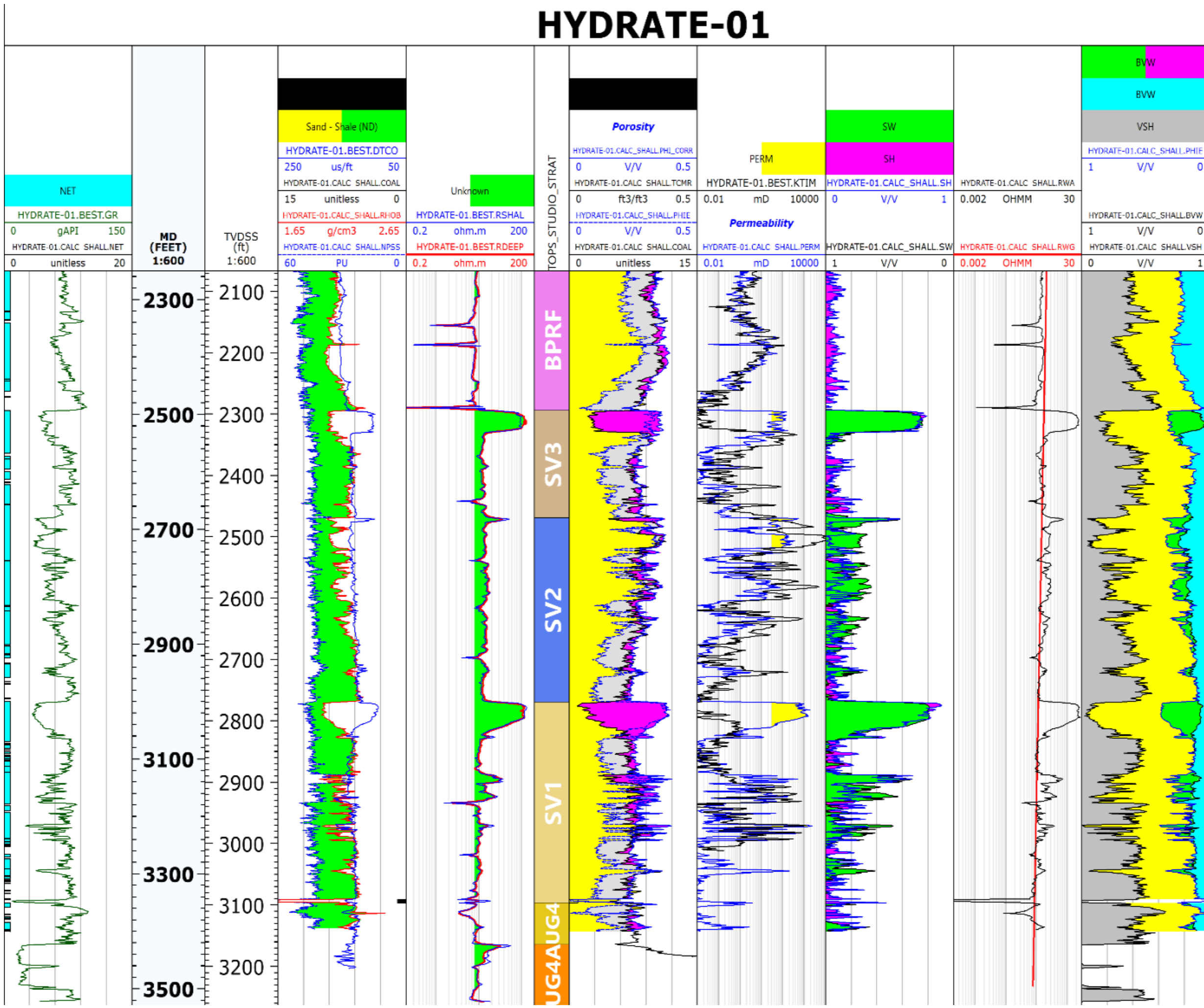


Modified from Lim et al., 2020 - ICGH10

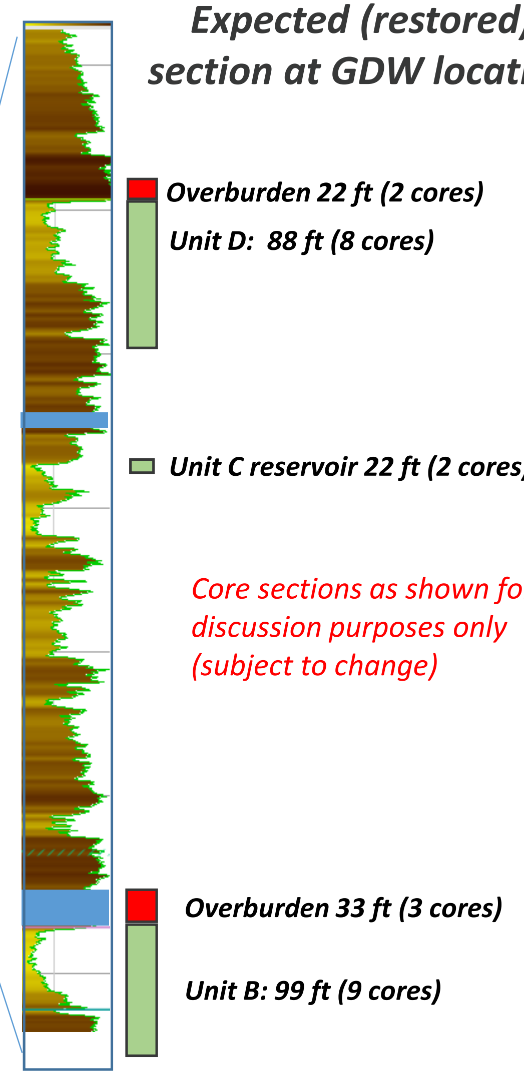
Geologic Data Well (GDW)

Pressure Coring Plan

24 HPTC-III Cores (11’ each) - TOTAL 264’ of Core



Expected (restored) section at GDW location



Core sections as shown for discussion purposes only (subject to change)

Modified from Boswell et al., 2020 - ICGH10

GDW Pressure Core Aanalysis

Laboratory Tools and Measurements

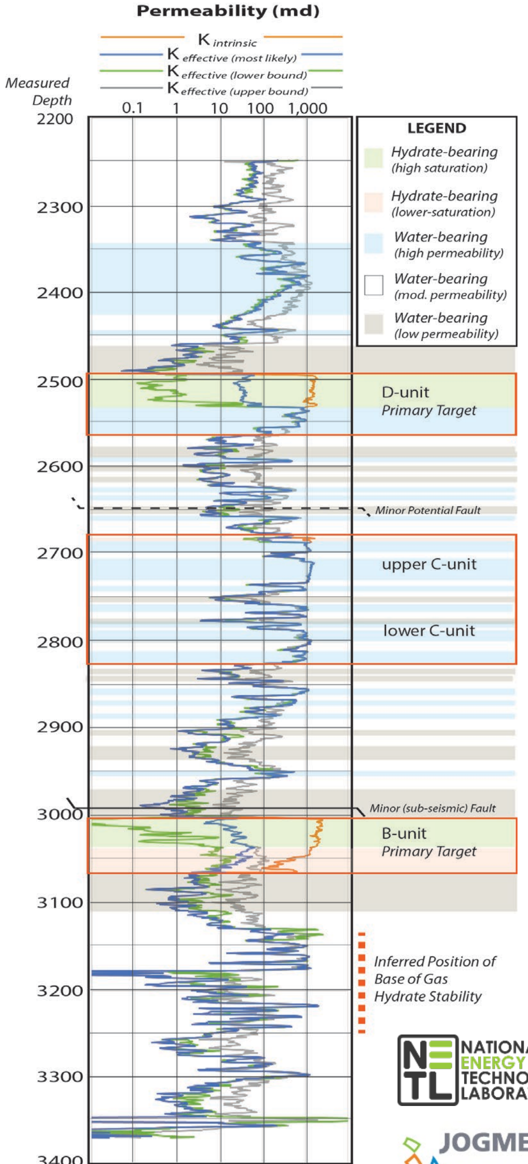
Institution	GEOTEK	GEOTEK	GEOTEK	AIST	AIST	GaTech	GaTech	NETL	NETL	NETL	USGS	USGS	USGS
Contact	Peter Schultheiss: peter.schultheiss@geotek.co.uk			Jun Yoneda: jun.yoneda@aist.go.jp		Sheng Dai: sheng.dai@ce.gatech.edu		Yongkoo Seol: yongkoo.seol@netl.doe.gov			William Waite: wwaite@usgs.gov		
Device	PCATS	PCATS Triaxial	K0-Permeameter	TACTT ~	High-pressure Oedometer Chamber	Permeability	Stiffness	Effective Stress Cell	Micro-CT	Anisotropic Perm	Direct Shear Cell	Effective Stress Cell	High-Effective Stress Permeability
On-site analysis	✓												
Sample Size (height, cm)	7.5 - 350 (variable)	11	2.5 - 8 (variable)	6 10	4	6	6	6 11	< 5	3.6	15 18	~6	6 10
physical properties													
Consolidation and Compressibility Coefficients		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Wave Velocity	Vp ✓	Vs ✓		Vp, Vs ✓			Vp, Vs ✓	Vp, Vs ✓			Vp ✓		
Poisson's Ratio		✓		✓	✓		✓	✓					
Ko (earth pressure at rest)							✓						
Bulk Density	✓												
Effective Permeability		Vert. ✓	Vert. ✓	Vert., Hor. ✓	✓	Vert., Hor. ✓		Vert. ✓	Vert. ✓			Vert. ✓	Vert. ✓
Intrinsic Permeability		Vert. ✓	Vert. ✓	Vert., Hor. ✓	✓	Vert., Hor. ✓		Vert. ✓	Vert. ✓	Vert., Hor. ✓		Vert. ✓	Vert. ✓
Relative Permeability								Vert. ✓				Vert. ✓	Vert. ✓
Triaxial Test		Com., ✓		Com., ✓	✓			Ext. ✓	Com., Ext. ✓				
Shear Strength		✓		✓							✓		
sediment properties													
Grain Size	✓			✓	✓	✓	✓				✓	✓	✓
Grain Density				✓	✓	✓	✓				✓	✓	✓
Specific Surface											✓	✓	✓
XRD				✓	✓	✓	✓				✓	✓	✓
Electrical Sensitivity											✓	✓	✓
Sedimentation/Fines Behavior											✓	✓	✓
gas properties													
Gas Chemistry	✓	✓	✓	✓	✓						See USGS chemistry-specific sheet		
Methane Isotopic Ratios				✓	✓								
Hydration Number				✓	✓								
core imagery													
X-Ray	✓			✓	✓			✓	✓	✓			
X-Ray CT	✓												
P-Wave Scans	✓												
X-Ray Micro CT									✓				
At pressure photos				✓									
Depressurized photos	✓	✓	✓	✓	✓			✓	✓	✓	✓	✓	✓
SEM						✓	✓				✓	✓	✓

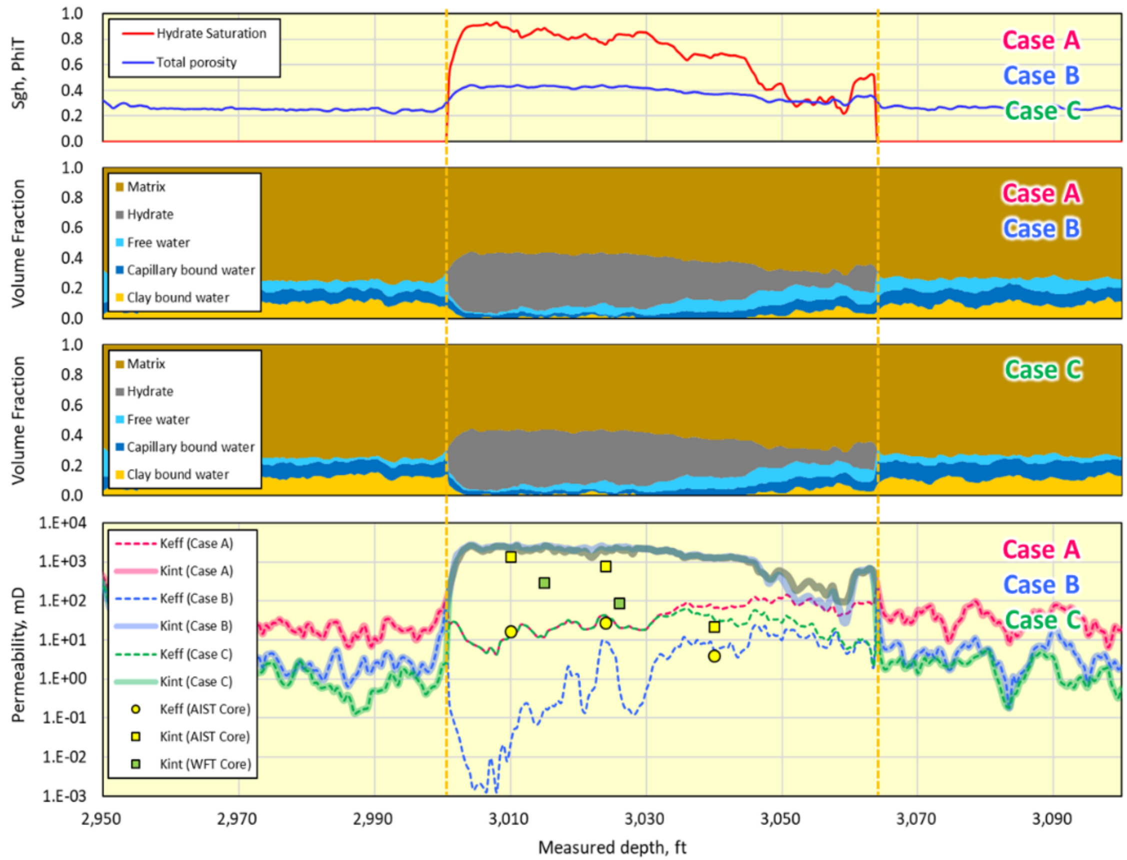
Prepared by William Waite (USGS) 08/19/2020

Gas Hydrate Production Modeling

Reservoir Properties

Boswell et al., 2020 - ICGH10
Myshakin et al., 2020 - ICGH10





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Three modeling cases to constrain gas and water rates

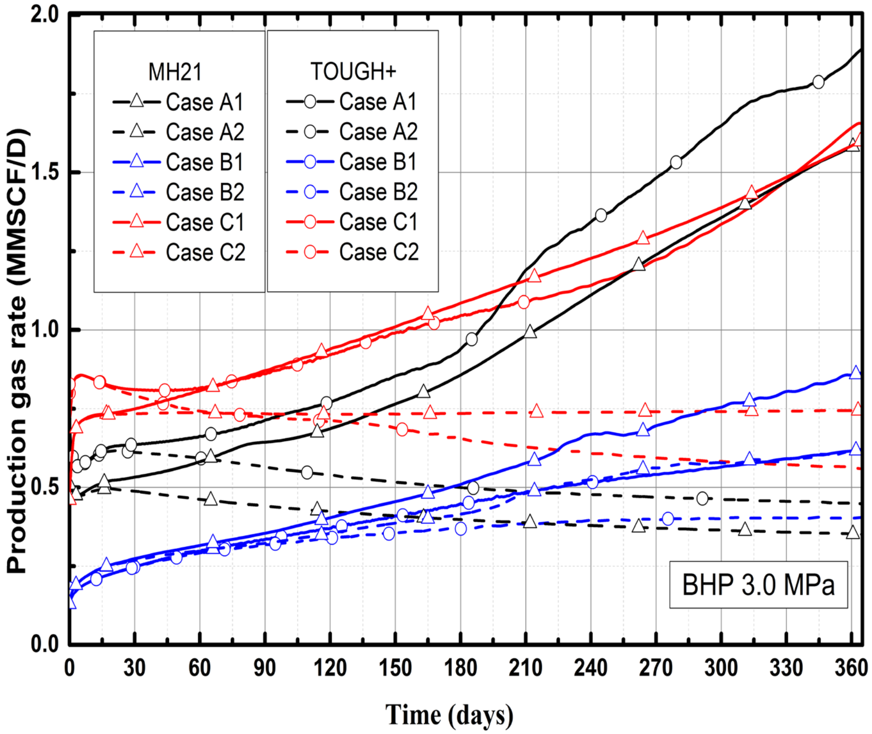
- Conservative case (CASE B) based on NMR- Ks
- Aggressive case (CASE A) core-corrected (entire section)
- Most Likely case (CASE C) core-corrected (main reservoir)

Initial Modeling Results

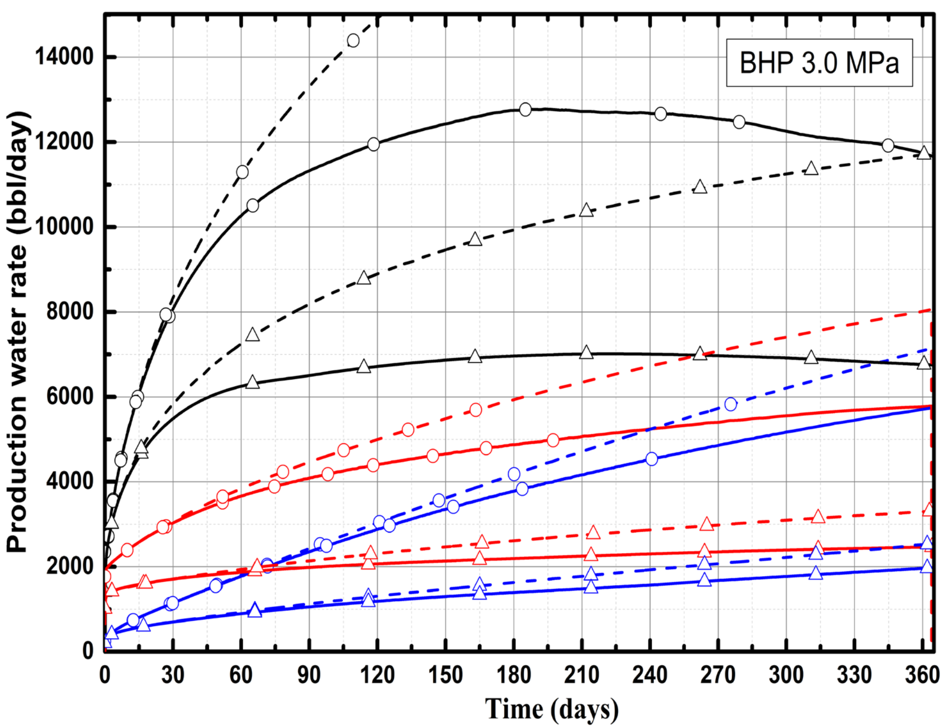
Code Comparison – Constraint on max gas and water rates to guide surface facility design

Assumption is continuous operations from undamaged reservoir (no geomechanics)
Case C1: Most likely geologic condition with confinement (500'): C2 = most likely condition without confinement (3,000')

GAS



WATER



The models differ in the way they assign mobility to liquid water formed during hydrate dissociation

Myshakin et al., 2020 - ICGH10

Key Components of Well Testing Plan

PTW Testing Operations

Base Production Method: Depressurization

- Maximize data interpretability by imparting a single driving force
- Employ a step-wise pressure reduction to maximize scientific insight and to minimize operational risks associated with large drawdowns
- First step at P > GHS to assess water mobility issues
- Additional pressure drawdowns set at ~2.0 mPa increments (to be refined via focused engineering studies)
- Follow well intervention/stimulation protocols where reservoir response dictates
- At end of test, impart largest feasible pressure drops

Summary

Alaska Gas Hydrate Production Field Experiment

Operational Test Plan

With the confirmation of viable reservoirs, the project proponents are proceeding into the next phase of the project, which will include the establishment of the test site, including:

(1) The installation of surface facilities.

(2) Drilling of a Geoscience Data Well (GDW) including full scientific logging, borehole geophysics, whole-round pressure coring and pressure-core site operations (core handling and storage), and installation of completion/monitoring equipment.

(3) Transport of samples to collaborating laboratories.

(4) Drilling, logging, and completion of production test well – 1 (PTW1) with completion in only Unit-B.

(5) Drilling, logging, and completion of PTW-2 with completion in both Units B and D.

(6) After a 3-month period to allow formation temperatures to equilibrate, conduct production testing operations in PTW1, consisting of step-wise pressure reduction and monitoring, with intervention as needed and with required surface operations including gas, water, solids sampling, handling, and disposal. Operations will continue in PTW-1 for as long a useful data are being obtained.

(7) Production testing operations in PTW2 (based on the findings from PTW-1).

(8) Periodic surface monitoring geophysical surveys when possible, without disruption to testing operations.

(9) Well abandonment and site reclamation.

Alaska Gas Hydrate Production Field Experiment

Abbreviations

Abbreviations

DAS	Distributed acoustic system
DEN	Density
DOE	US Department of Energy
DSS	Distributed shear system
DTS	Distributed temperature system
GDW	Geoscience Data Well
G&G	Geologic and Geophysical
GH	Gas hydrate
IA	Interagency Agreement
JOGMEC	Japan Oil, Gas and Metals National Corporation
LWD	Logging while drilling
PBU	Prudhoe Bay Unit
PRA	Petrotechnical Resources of Alaska
P/T	Pressure and temperature
PTW-1	Production Test Well Number 1
PTW-2	Production Test Well Number 2
MPU	Milne Point Unit
NMR	Nuclear magnetic resonance
SOR	Statement of Requirements
STW	Stratigraphic Test Well (Hydrate-01)
TAS	Temperature Array Sensors
TPO	Third Party Operator
USGS	US Geological Survey
Vgh	Gas hydrate saturation
Vp	Compressional velocity
Vs	Sheer velocity
VSP	Vertical seismic profile