Alaska Gas Hydrate Production Field Experiment Reservoir Response Test Planning, Operations, and Results Analysis Support

Agency Agreement Tracking Number
898243321SFE000024

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U.S. Geological Survey

U.S. Department of Energy

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Presentation Outline

- Program Overview – Goals and Objectives
- Technology Background
- Technical Status/Project Scope
- Accomplishments and Planning
  - Test site review and characterization
  - Field test technical planning support
- Field Operations and Data Analysis
- Project Summary

Project Overview

– Funding (FY-2021 through FY-2023)

DOE $231,124

USGS $985,000

– Performance Dates

09/01/2021 – 08/30/2026

– Project Participants

Tim Collett (PI), Seth Haines, Rita Zyrianova, Sam Heller

– Overall Project Objectives

Geologic and geophysical technical support

Project Overview

Goals and Objectives

This project is designed as a cooperative research effort, with USGS providing technical geoscience support in a partnership that includes DOE and the Japan Organization for Metals and Energy Security (JOGMEC). The primary objective of this DOE-USGS Interagency Agreements (IA) is to provide geologic and geophysical technical support to the Alaska Gas Hydrate Production Field Experiment. The specific goals of this cooperative effort is to support the planning, operations, and analysis of the technical results of the Alaska North Slope Extended Gas Hydrate Production Test.

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 has included the drilling and evaluation of a stratigraphic test well (completed in December 2018), followed by the establishment of a production test site in 2022-2023 (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 that started in October 2023.

Project Update Link: DOE and International Partners Start to Conduct Gas Hydrates Production Testing on the Alaska North Slope | Department of Energy

Technical Status/Project Scope

Period of Performance: 09/01/2021 – 08/30/2026

Task: Gas Hydrate Production Testing Support

Subtask 1.1: Gas hydrate field test technical planning support

The USGS shall provide technical guidance in support of the DOE/JOGMEC Extended Gas Hydrate Production Test in the Eileen Gas Hydrate Accumulation on the Alaska North Slope.

Subtask 1.2: Gas hydrate field test technical and operational support

(1) Provide technical and scientific leadership and advice for formulation and operation of a research drilling and production testing program designed to assess the nature and production potential of methane hydrates on the Alaska North Slope and (2) provide personnel and resources to enhance field and laboratory analyses of material and data recovered by coring, downhole logging, and geophysical characterization.

Subtask 1.3: Analysis of gas hydrate field test geologic and production test data

The Project Science-Operational plan will be further developed and refined under this agreement by the USGS and DOE in order to synthesize and analyze the logging, direct sampling, geophysical and geologic data acquired during the testing phase of the Alaska project.

Plans for Ongoing & Future Testing

Alaska Gas Hydrate Production Field Experiment: Operation and Science

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
-Testing Results Analysis

3. Well-Based Data Acquisition and Analysis

-Mud Logging Program
-Downhole LWD/Wireline Logging Program
-Pressure Coring Operations
-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
-4D VSP/CWT Geophysical Data Acquisition (under review): Test Site Characterization and Production Monitoring

Plans for Ongoing & Future Testing

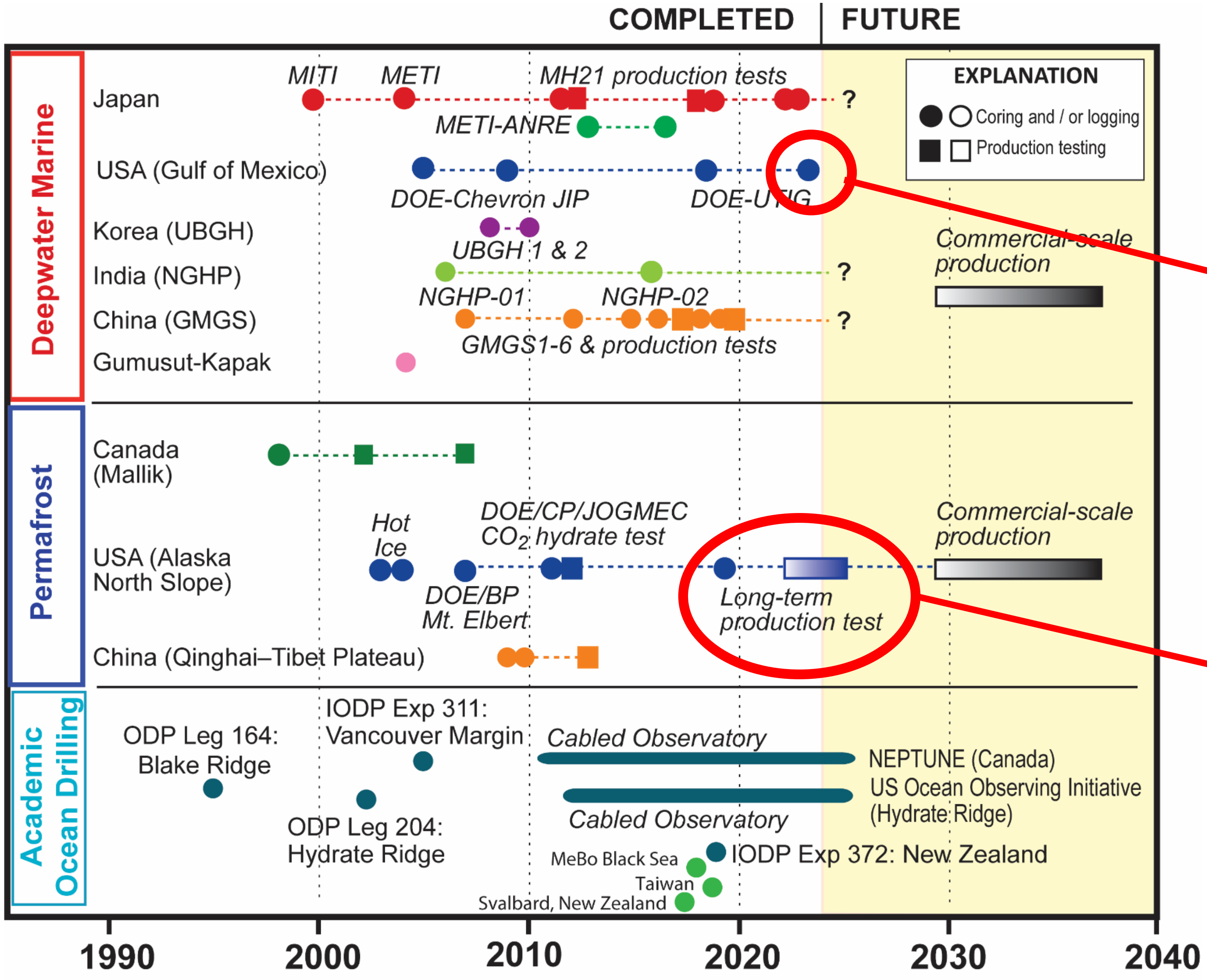
Alaska Gas Hydrate Production Field Experiment: Operation and Science

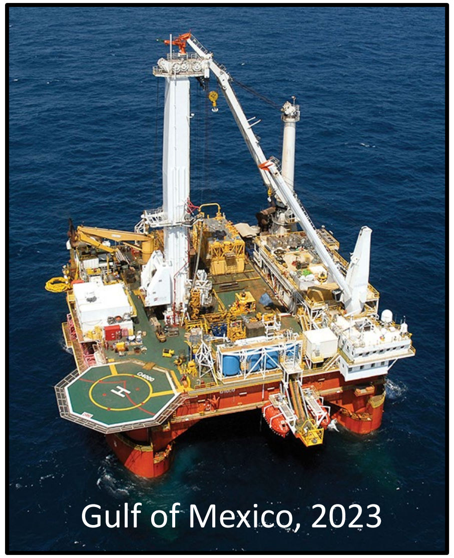
5. Project Data Analysis Plan

1. Field operational, production, geologic, geophysical data integration
2. Field and post-field core lab data analysis and integration
3. Partner core lab data analysis and integration
4. Contractor core lab data analysis and integration
5. Well log data integration and analysis
6. Geophysical data integration and analysis
7. Production and monitoring data integration and analysis
8. Operational Review - Well and test design
9. Operational Review - Surface and test facilities
10. Gas hydrate production forecasting and history matching
11. Geomechanical data analysis and integration with production testing data
12. Energy balance - Design of next stage stimulation to maximize gas rates

USGS will support DOE-led gas hydrate production modeling efforts, including the preparation of reservoir model input from available production data, and contribute to DOE led gas hydrate production modeling calibration studies.

Gas Hydrate Scientific and Industry Drilling Projects





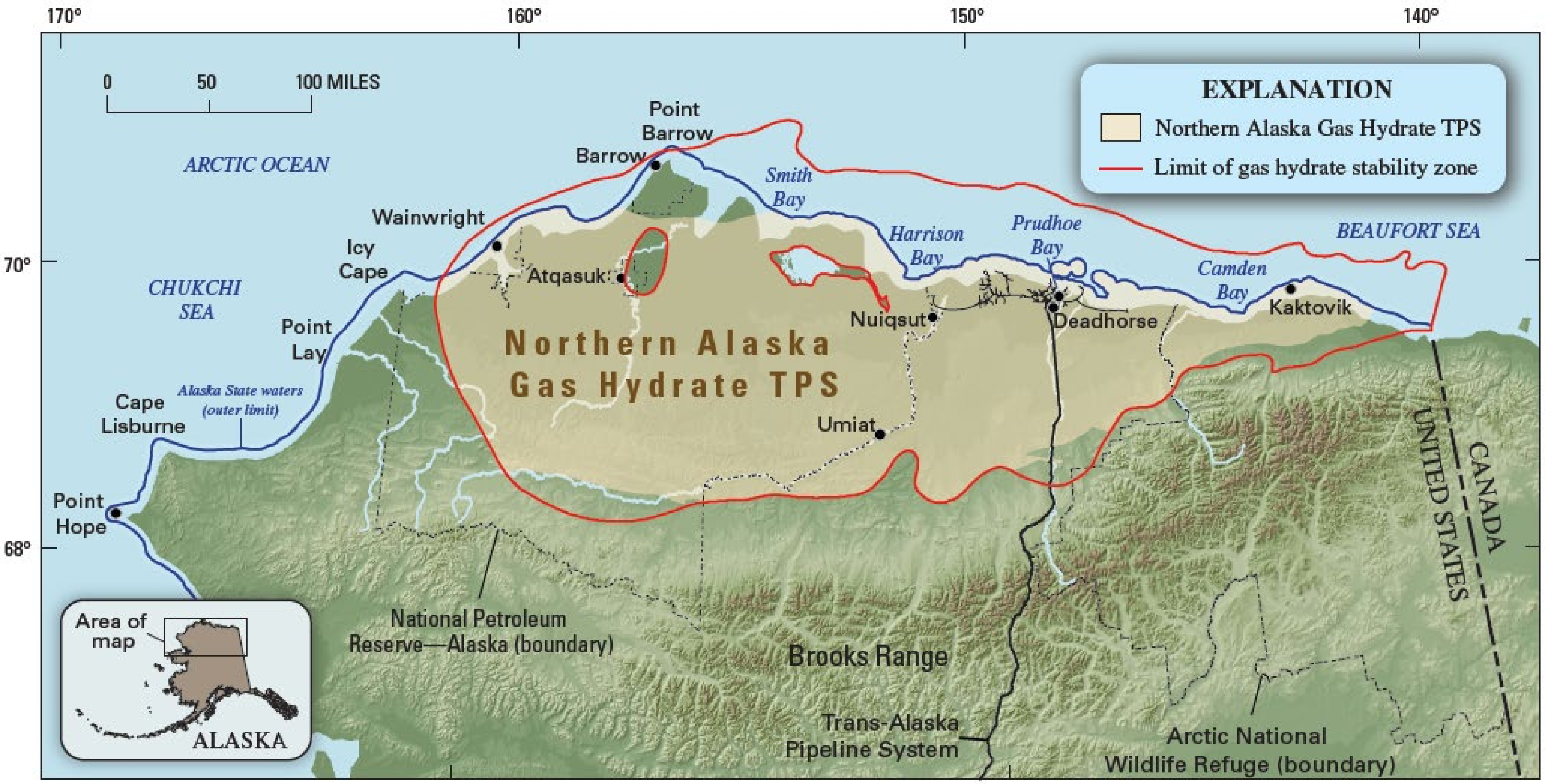
Gulf of Mexico, 2023

Alaska North Slope, 2022-2024

USGS science for a changing world

Alaska North Slope

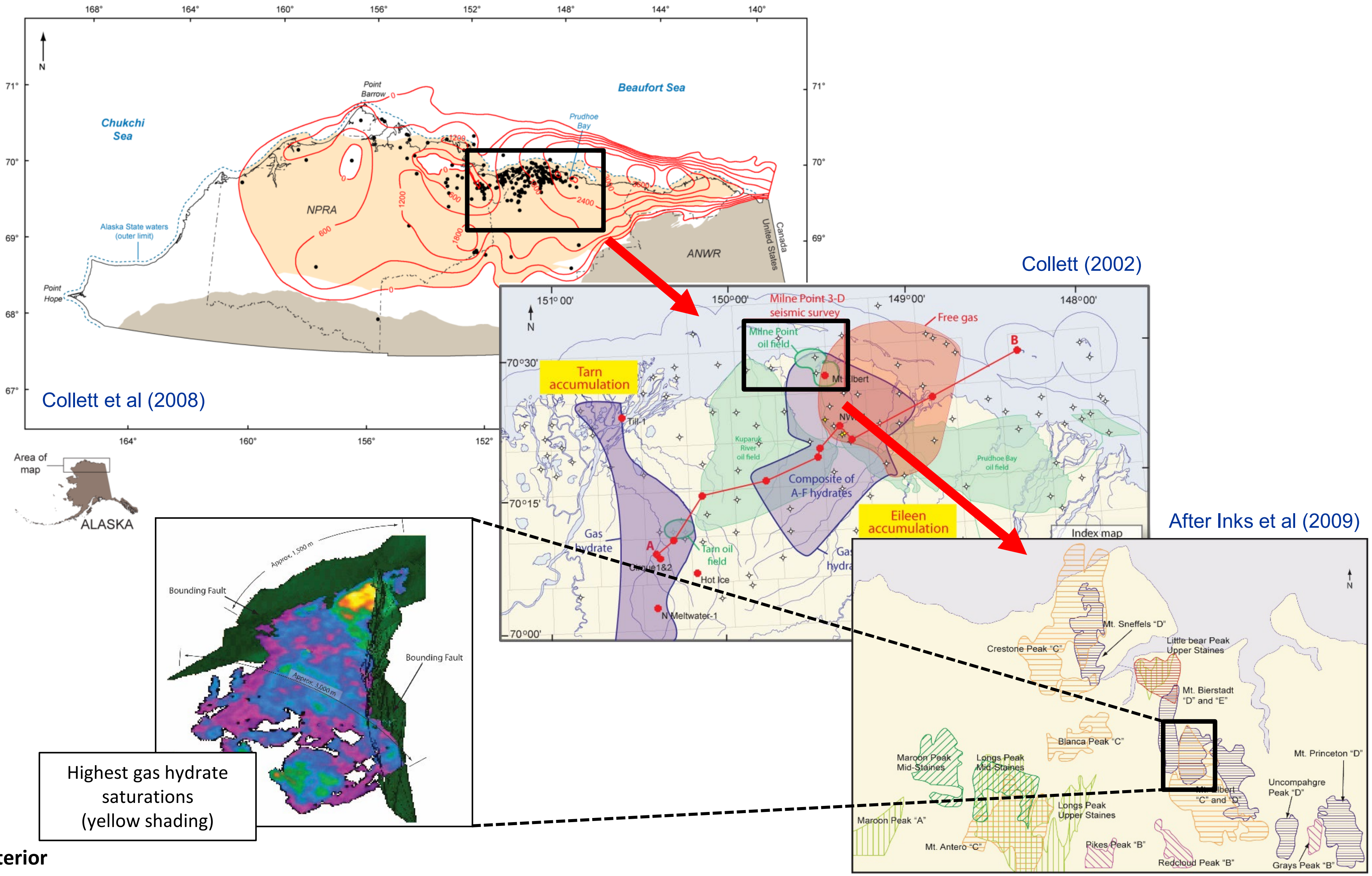
Gas Hydrate Geologic & Production Testing



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

Controls on the Occurrence Gas Hydrate

Gas Hydrate TPS to Gas Hydrate Accumulations



2018 USGS Alaska Gas Hydrate Assessment

NAGA Assessment Results

Collett et al., USGS 2018

Total petroleum system and assessment units (AUs)	AU probability	Accumulation type	Total undiscovered resources							
			Gas (BCFG)				NGL (MMBNGL)			
			F95	F50	F5	Mean	F95	F50	F5	Mean
Northern Alaska Gas Hydrate Total Petroleum System										
Nanushuk Formation Gas Hydrate AU	0.9	Gas	0	19,978	46,706	21,511	0	0	0	0
Tuluvak-Schrader Bluff-Prince Creek Formations Gas Hydrate AU	0.9	Gas	0	16,231	38,449	17,608	0	0	0	0
Sagavanirktok Formation Gas Hydrate AU	0.9	Gas	0	13,840	30,475	14,677	0	0	0	0
Total undiscovered conventional resources			**0**	**50,049**	**115,630**	**53,796**	**0**	**0**	**0**	**0**

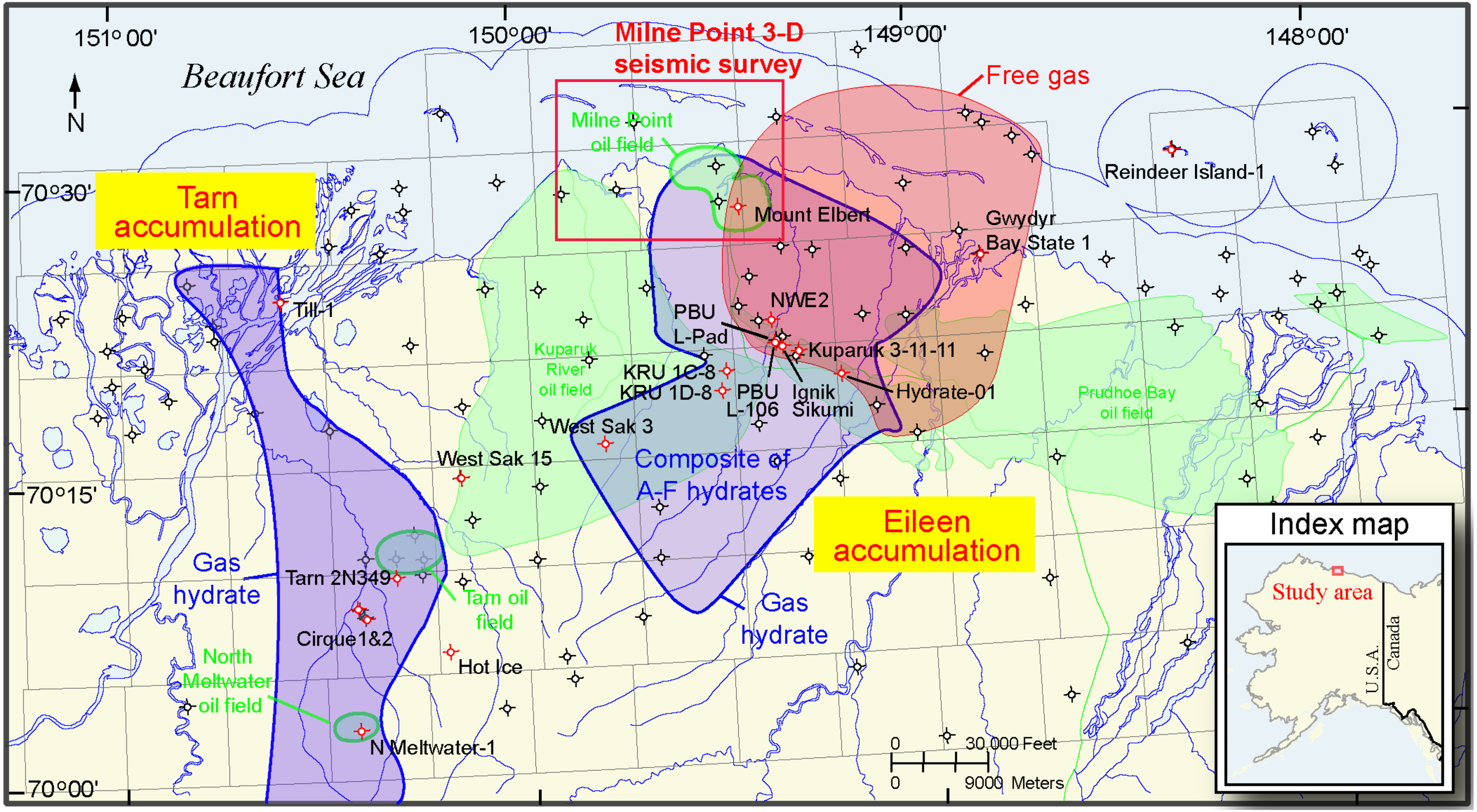
Of the estimated 54 TCF of gas within hydrates on the North Slope, 48 percent occurs on federally managed lands, 45 percent on lands and offshore waters managed by the State of Alaska, and 7 percent on Native lands.

Comparison Alaska Gas Hydrate with Other Domestic Resources

- Undiscovered gas AK offshore estimated at ~105 TCF (BOEM)
- Undiscovered gas AK onshore estimated at ~100 TCF (USGS)
- Undiscovered gas hydrate AK onshore estimated at ~54 TCF (USGS)
- Marcellus Shale, Appalachian Basin estimated at ~84 TCF (USGS)
- Mancos Shale, Piceance Basin (CO/UT) estimated at ~66 TCF (USGS)

Eileen and Tarn Gas Hydrate Trends

Collett et al., AAPG 1992



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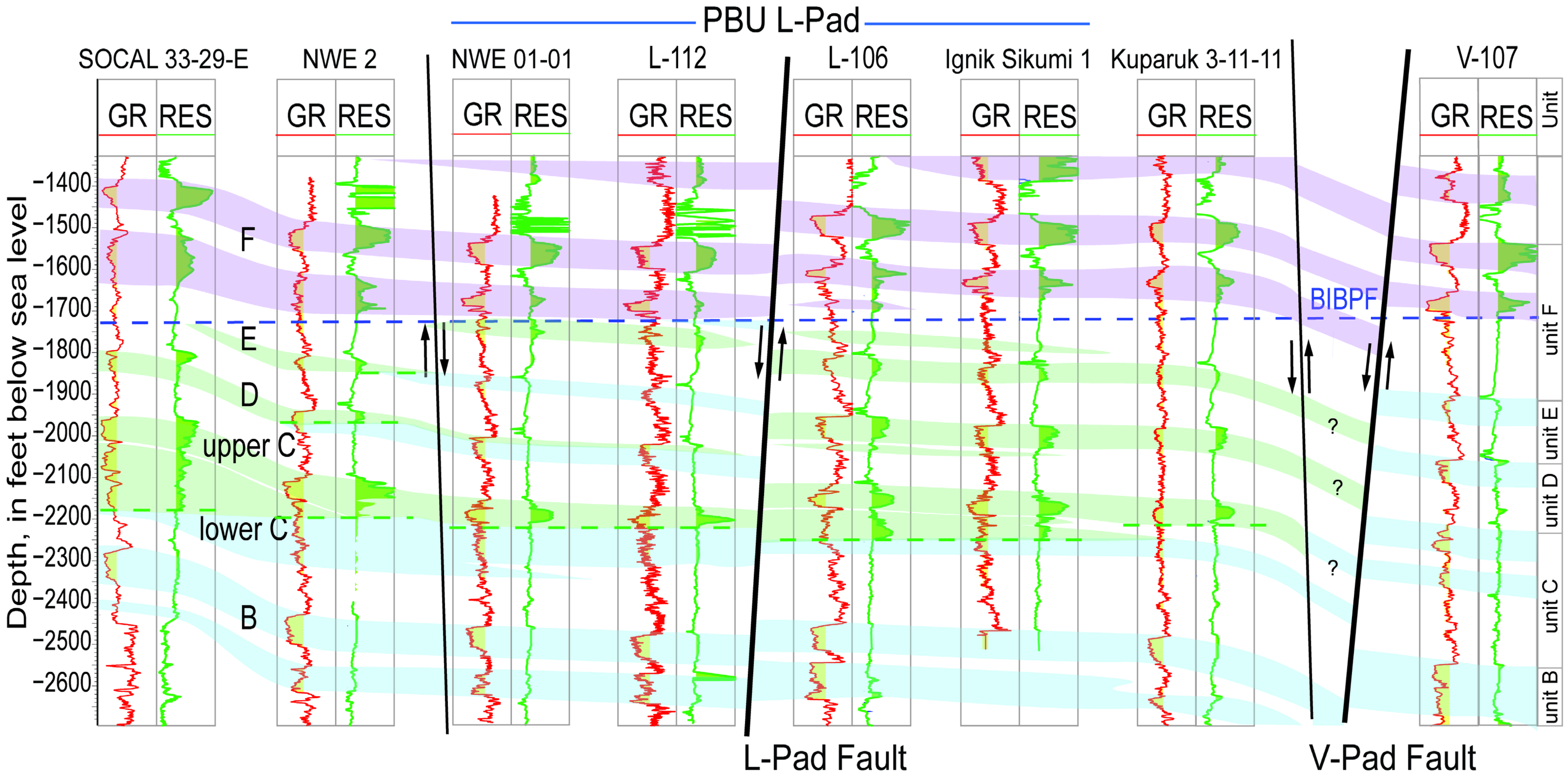
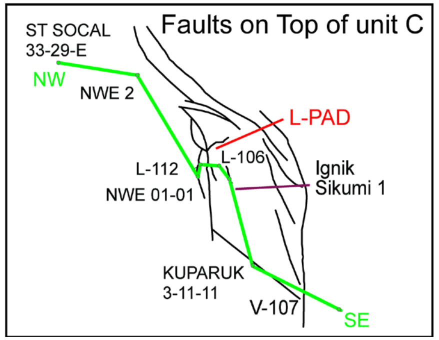
science for a changing world

Eileen Gas Hydrate Trend

Greater PBU L Pad Area – Well log Correlation Section

Boswell et al., Energy Fuels 2022



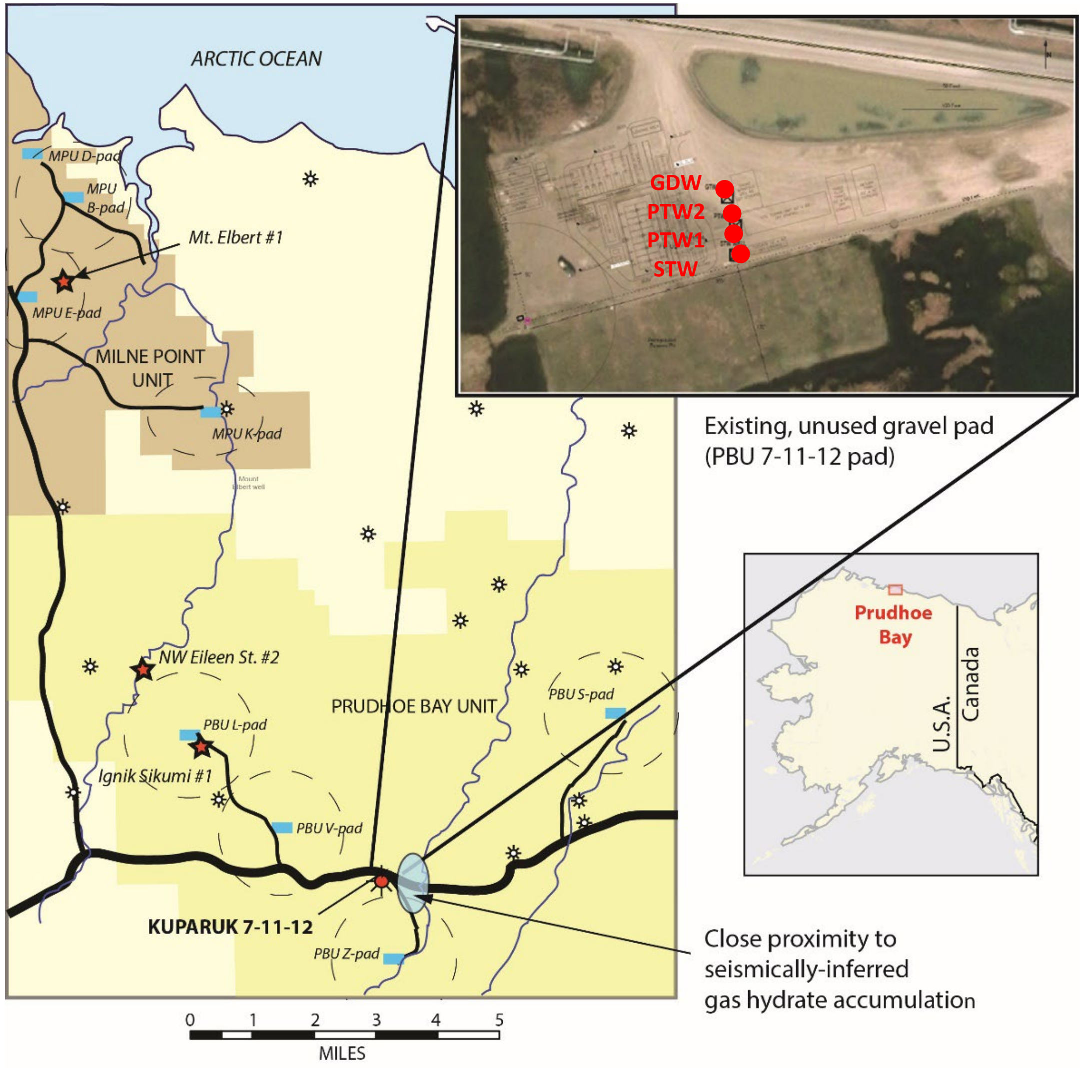


Ice- or hydrate-bearing sand
Hydrate-bearing sand
Water-bearing sand
Hydrate-water contact
Gamma ray (GR scale 10-120 API)
Resistivity (RES scale 2-2000 ohm-m)

Alaska North Slope

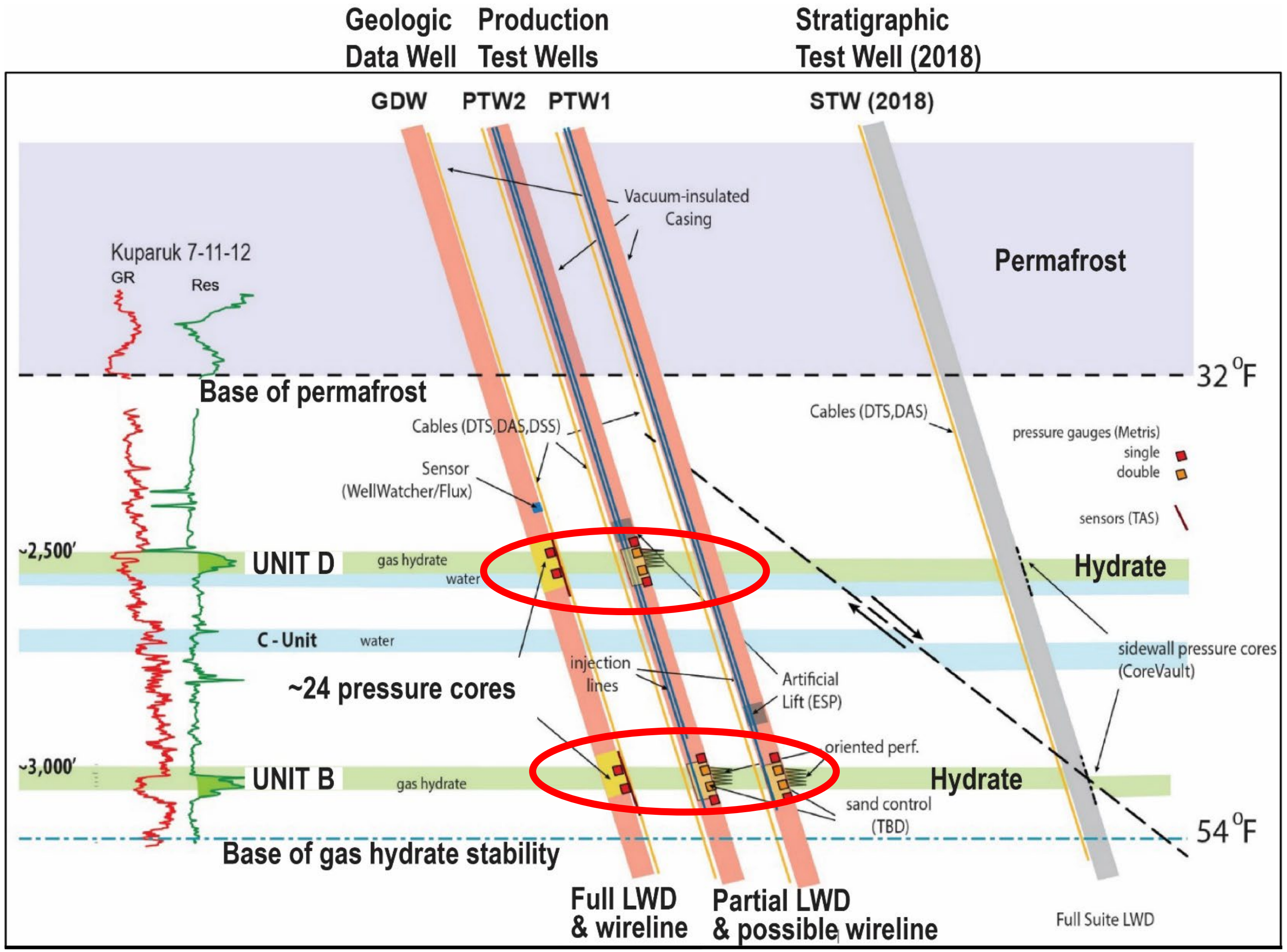
Extended Gas Hydrate Production Testing – PBU Site Review

- 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.**



Alaska North Slope

Extended Gas Hydrate Production Testing



- Assess technologies to safely produce hydrates
- Long-term (~9 months) production test started in Oct 2023
- Focusing on sub-permafrost gas hydrate in discrete sedimentary sections (Units B and D), with pressure core and well log data acquired in 2022
- Joint USGS-DOE-JOGMEC operation with ASRC-AES as operator
- Production through stepwise depressurization, with continuous monitoring and sampling of produced fluids and gas (USGS)
- Advanced, pressure/temperature gauges and distributed temperature, acoustic, and strain sensing and 4D VSP & CWT (?) monitoring of reservoir changes during production; VSP and DTS analysis with CSM (MOU)
- Includes hazards (land subsidence) monitoring

JOGMEC · U.S. DEPARTMENT OF ENERGY · USGS science for a changing world · ASRC ENERGY SERVICES a subsidiary of Arctic Slope Regional Corporation · AIST NATIONAL INSTITUTE OF ADVANCED INDUSTRIAL SCIENCE AND TECHNOLOGY (AIST)

Alaska Gas Hydrate Production Field Experiment

Extended Gas Hydrate Production Testing

October 2022 – Drilling Operations

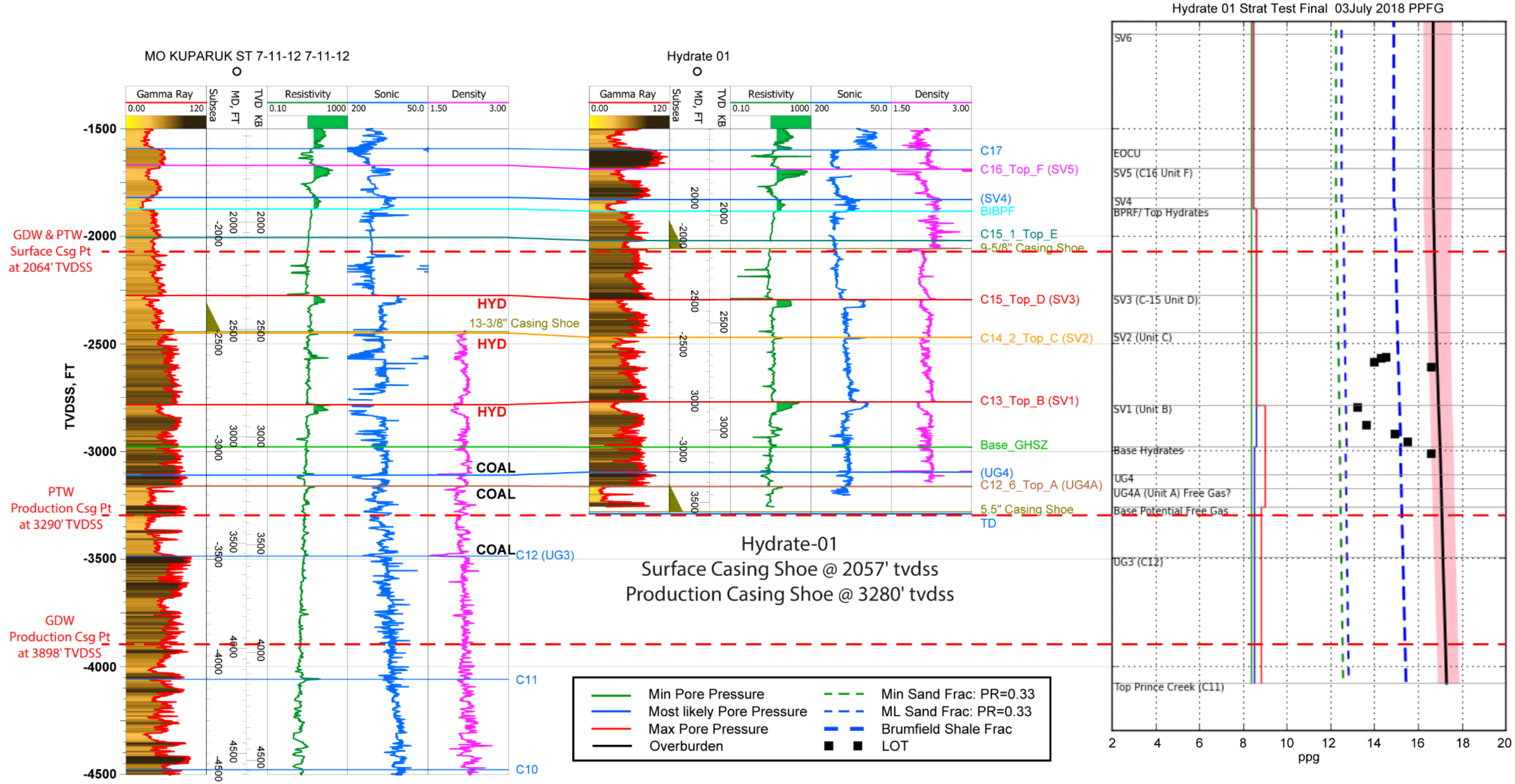
September 2023 – Testing Operations

[Project Update Link: DOE and International Partners Start to Conduct Gas Hydrates Production Testing on the Alaska North Slope | Department of Energy]

Alaska Gas Hydrate Production Test Site

Lithostratigraphic/Geomechanical Framework

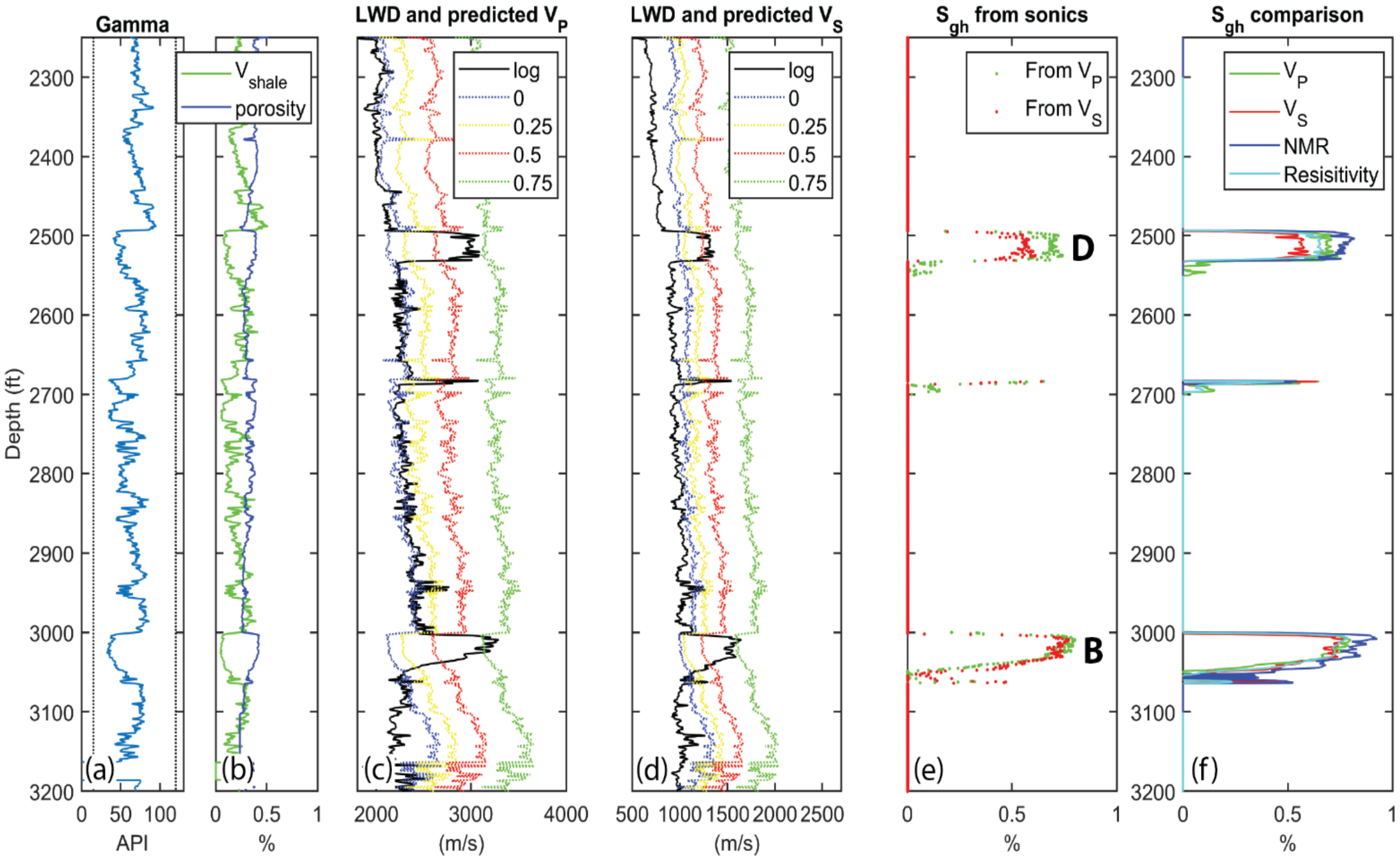
Collett et al., Energy Fuels 2022



PBU Hydrate-01 Stratigraphic Test Well

Well Log Analysis

Haines et al., Energy Fuels 2022



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

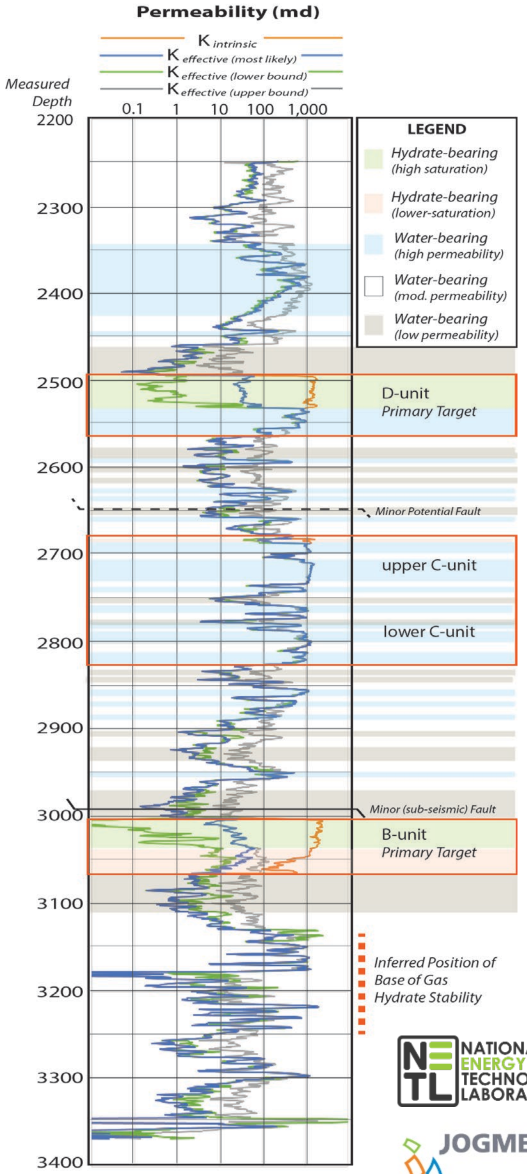
e. Predicted V_S and V_P Gas hydrate saturations (S_{gh})

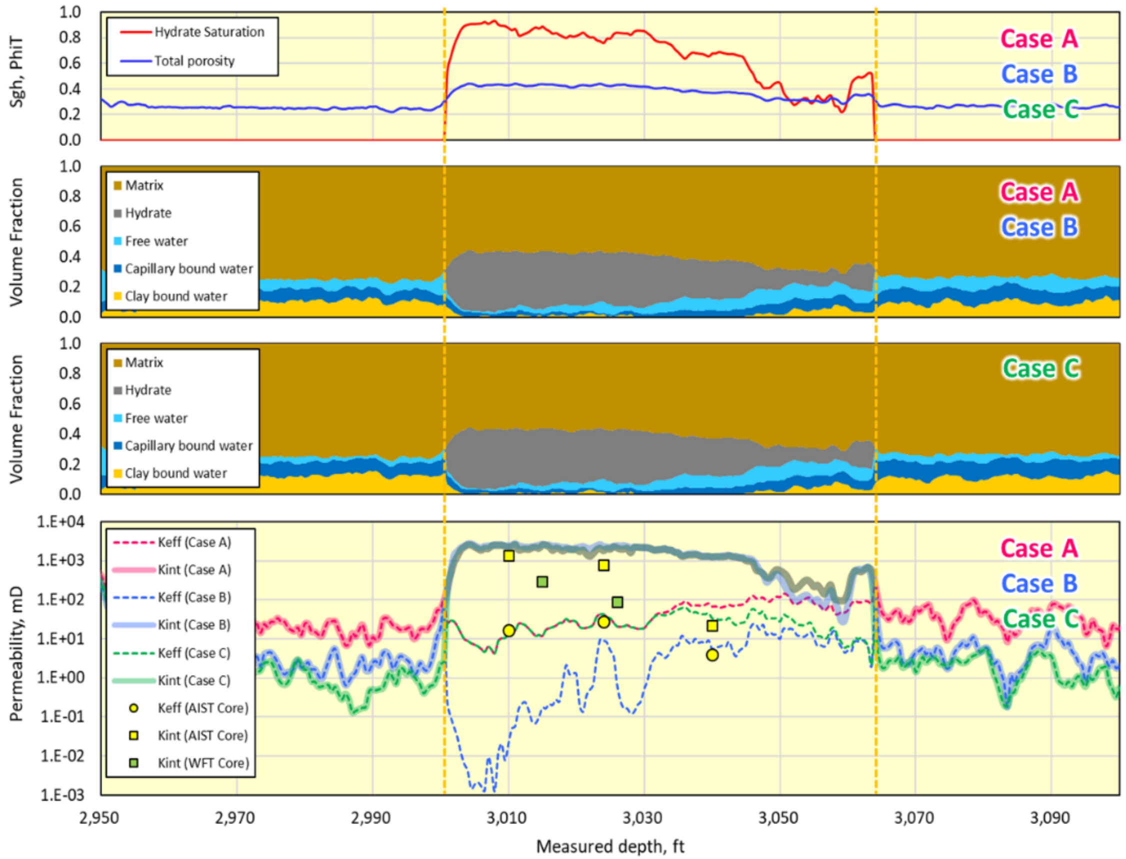
f. Comparison of S_{gh} estimated from V_P and V_S, NMR-DEN porosity, and resistivity LWD-measurements

Gas Hydrate Production Modeling

Reservoir Properties

Boswell et al., Energy Fuels 2022
Myshakin et al., Energy Fuels 2022





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)

Test Well Monitoring

DAS *4D VSP Geophysical Monitoring*

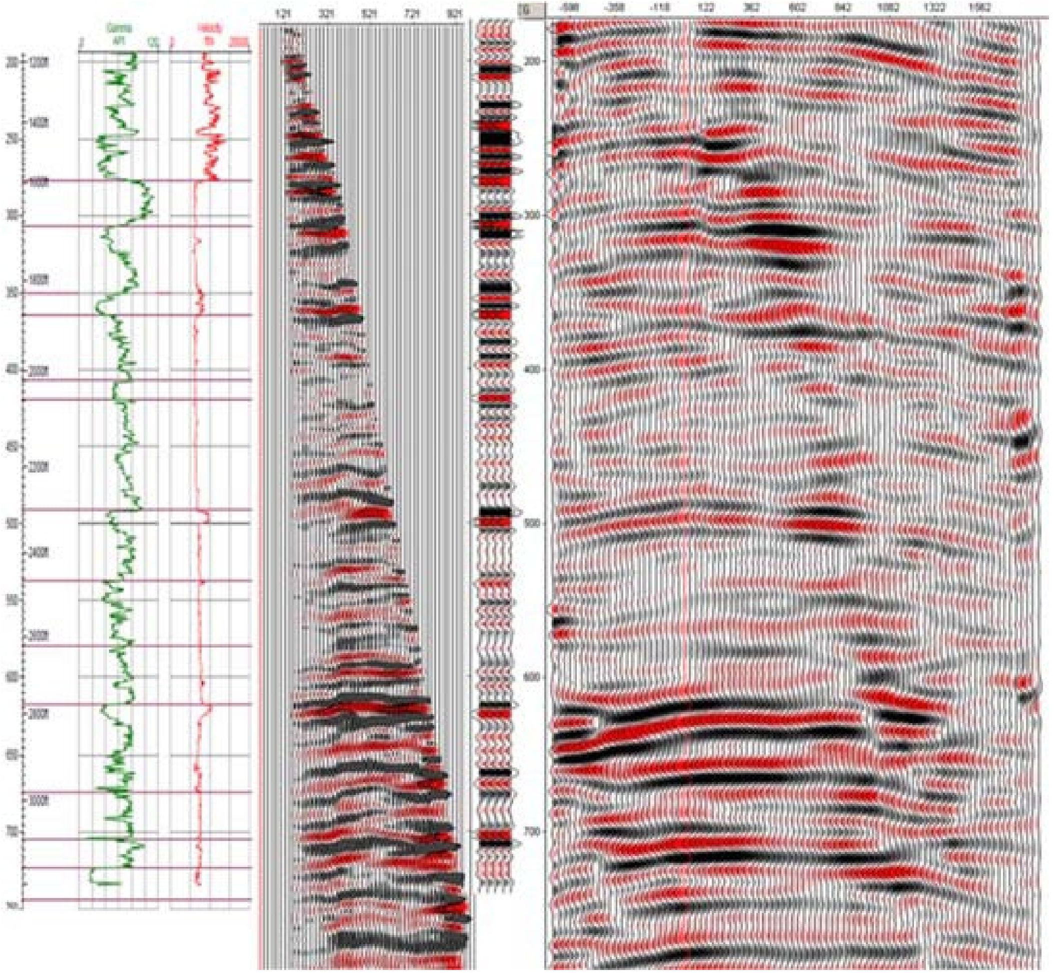
Young et al., Energy Fuels 2022

Monitoring reservoir changes during testing

- Time-lapse DAS VSP data (under review)
  - Acquire surveys before and after production test
  - 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) 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:** Accessible for production logging: Directional Gyro, cement evaluation
- **GDW:** Pressure-coring (HPTC) Units D and B reservoir and bounding units, with lab support
- **GDW-PTW Mud-logging:** Industry contract with cuttings and gas samples

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- **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

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- **PTWs Monitoring:** Fluids (gas and produced formation water) volumes and rates, produced solids, and gas/water chemistry real time and samples, etc.
- **GDW Monitoring:** DTS-DAS-DSS, temperature and pressure gauges behind casing
- **PTWs Monitoring:** DTS-DAS-DSS, temperature and pressure gauges behind casing

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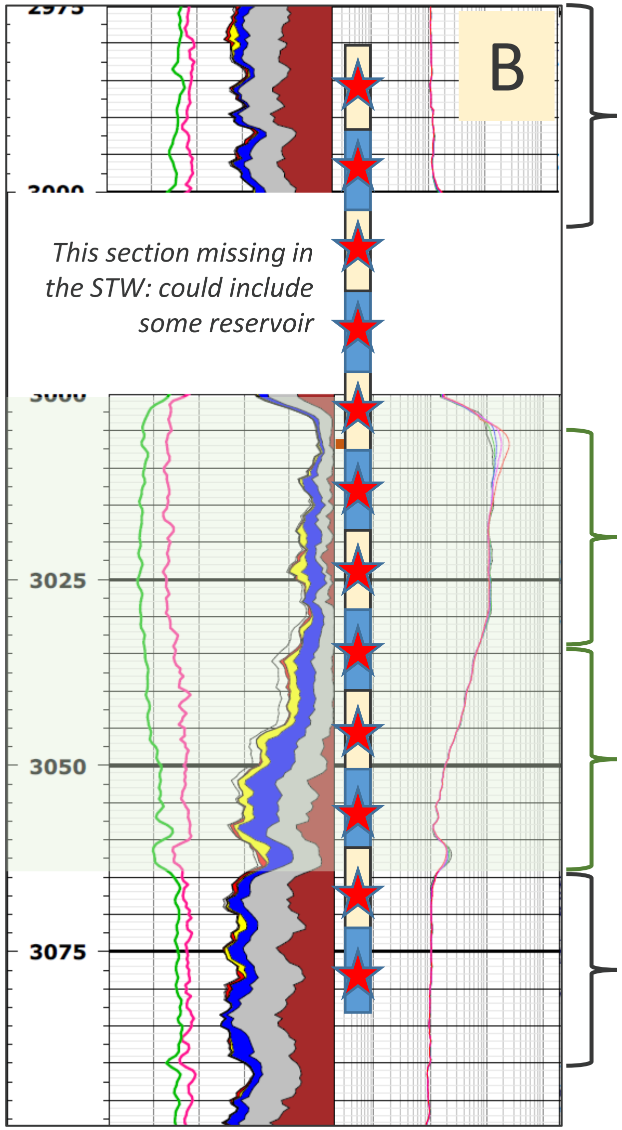
- **STW, GDW, PTWs Monitoring:** VSP and X-hole geophysical data acquisition/analysis

Pressure Core Sample Requests and Master Sample Plan

Master core sample plan linked the project's <u>priority properties</u> to proposed measurements by targeting "<u>zones of interest</u>" as well as whole reservoir "<u>profile measurements</u>".



"Zones of Interest"

- Upper Seal
- Upper Reservoir
- Lower Reservoir
- Lower Seal

Priority Properties

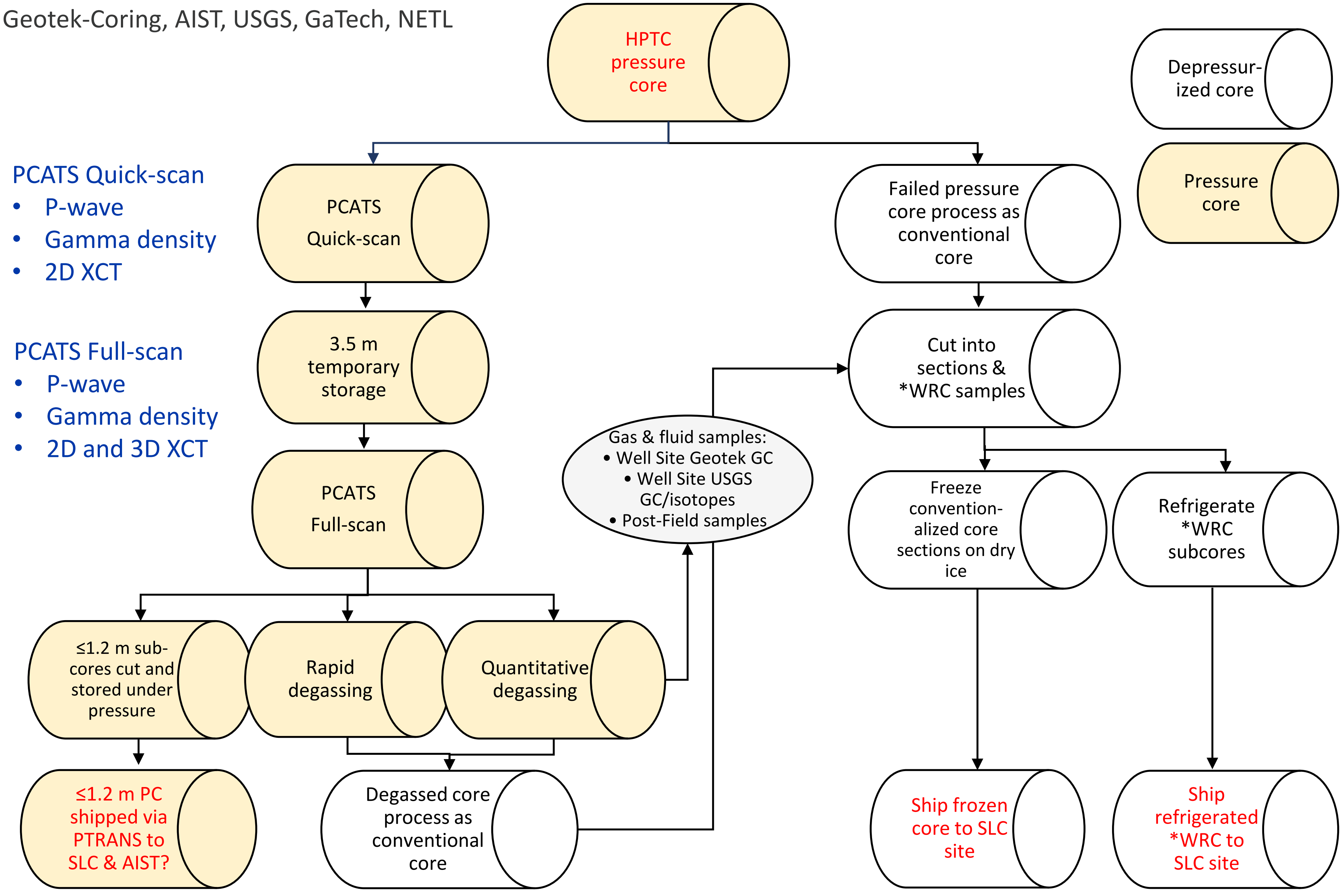
- Permeability
  - Direct vertical permeability
  - Direct horizontal permeability
  - Relative Permeability
  - Intrinsic Permeability
- Compressibility
- Mineralogy
- Poisson's Ratio
- Porosity
- Shear Strength
- Stiffness

"Profile measurements"

- Grain size
- Grain density
- Gas chemistry
- Sediment chemistry

Pressure Core Processing - Well Site Operations

Pressure Core Analysis: Geotek-Coring, AIST, USGS, GaTech, NETL



*WRC samples include samples for (1) lithostrat/solid geochemistry, physical/mechanical properties, organic/inorganic chemistry, microbiology.

Pressure Core Sample Requests and Master Sample Plan

Properties cover the requested priorities, with additional items to support broader scientific investigations of the reservoir formation and behavioral controls

Lithostratigraphy/solid geochemistry

- Bulk XRD
- Clay XRD
- Total N
- Total S
- Bulk $\delta^{13}C$, $\delta^{15}N$, $\delta^{34}S$
- Total C & TOC
- $CaCO_3$
- SEM
- SEM/EDS solid geochemistry
- Core Photos
- Thin Sections
- Core CT and X-ray scans
- MicroCT

Physical/geomechanical

- Porosity
- Hydrate saturation
- Hydrate grain size
- Grain Size
- Grain Specific Surface Area
- Grain Density
- Grain Shape
- Capillary Pressure
- NMR T2
  - Porosity
  - Pore size
  - NMR permeability
  - Bound/free water
- Permeability
  - Direct vertical permeability
  - Direct horizontal permeability
  - Relative Permeability
  - Intrinsic Permeability
- Shear Strength
- Stiffness
- Compressibility
- Poisson's Ratio
- Ko
- Vp
- Vs
- Thermal Properties
  - Thermal Conductivity
  - Heat Capacity
- Sand production
- Fines behavior
- Liquid Limit
- Electrical Sensitivity

Pressure Core Analysis: Geotek-Coring, AIST, USGS, GaTech, NETL

Pressure Core Sample Requests and Master Sample Plan

Properties cover the requested priorities, with additional items to support broader scientific investigations of the reservoir formation and behavioral controls

Pore water chemistry

- Salinity
- Alkalinity & pH
- DIC & DOC
- Cations/Anions
  - Cl, Br, SO_4, NO_3, F,
  - Ca, Na, Mg, K, Sr, Li
- $\delta^{13}C$-DIC
- $\delta^{18}O$, δD
- $\delta^{7}Li$

Gas

- Hydration number
- $C_1 – C_6$
- N_2 O_2 CO_2
- $\delta^{13}C-CH_4$
- $\delta D-CH_4$
- $\delta^{13}C-CO_2$
- $\delta^{13}C-C_2H_6$

Microbiology

- DNA
- RNA
- Lipids
- Total cell counts
- Urease activity
- Drilling Fluids
- PCATS Fluids

Produced Water

- Cations/Anions
  - Cl, SO_4
  - Ca, Mg, K, Sr
- $\delta^{18}O$, δD
- $C_{10}-C_{32}$ concentrations
- Conductivity/Salinity

Produced Gas

- $C_1 – C_6$
- N_2 O_2 CO_2
- $\delta D-CH_4$
- $\delta^{13}C-CH_4$
- $\delta^{13}C-C_2H_6$
- $\delta^{13}C-C_3H_8$
- $\delta^{13}C-CO_2$

Pressure Core Analysis: Geotek-Coring, AIST, USGS, GaTech, NETL

Pressure Core Analysis

Physical, Mechanical, Sedimentary, Geochemical Properties

Device	GEOTEK	AIST		GaTech		NETL			USGS		
Device	PCATS PCATS-Tri KO-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	PCATS Only										
Sample Size (height, cm)	11 (variable)	6 10	4	6	6	6 11	< 5	3.6	15 18	< 30	6 10
physical properties											
Consolidation and Compressibility Coefficients	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Wave Velocity	Vp, Vs ✓	Vp, Vs ✓			Vp, Vs ✓	Vp, Vs ✓			Vp ✓		
Poisson's Ratio	✓	✓	✓		✓	✓					
Effective Permeability	Vert. ✓	Vert., Hor. ✓	✓	Vert., Hor. ✓		Vert. ✓	Vert. ✓			Vert. ✓	Vert. ✓
Intrinsic Permeability	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		✓	✓								
Methane Isotopic Ratios		✓	✓							See USGS chemistry-specific sheet	
Hydration Number		✓	✓								
core imagery											
X-Ray	✓	✓	✓			✓	✓	✓			
X-Ray CT	✓										
Density & P-Wave Scans	✓										
X-Ray Micro CT							✓				
At pressure photos		✓									
Depressurized photos	✓	✓	✓			✓	✓	✓	✓	✓	✓
SEM				✓	✓				✓	✓	✓

Pressure Core Analysis: Geotek-Coring, AIST, USGS, GaTech, NETL

Test Well Monitoring

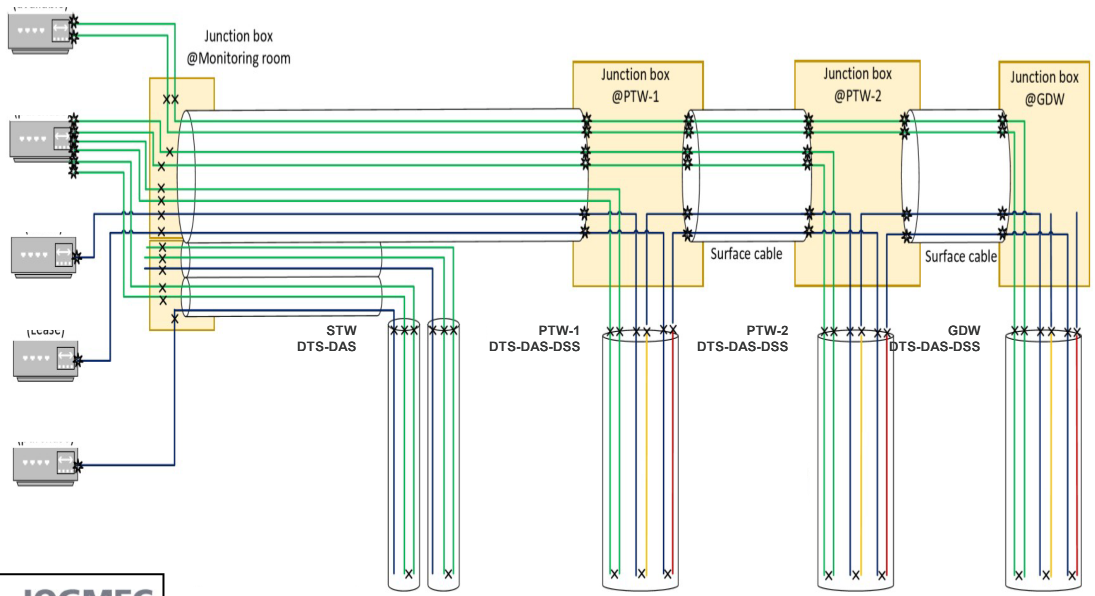
Distributed and Gauge Based Systems

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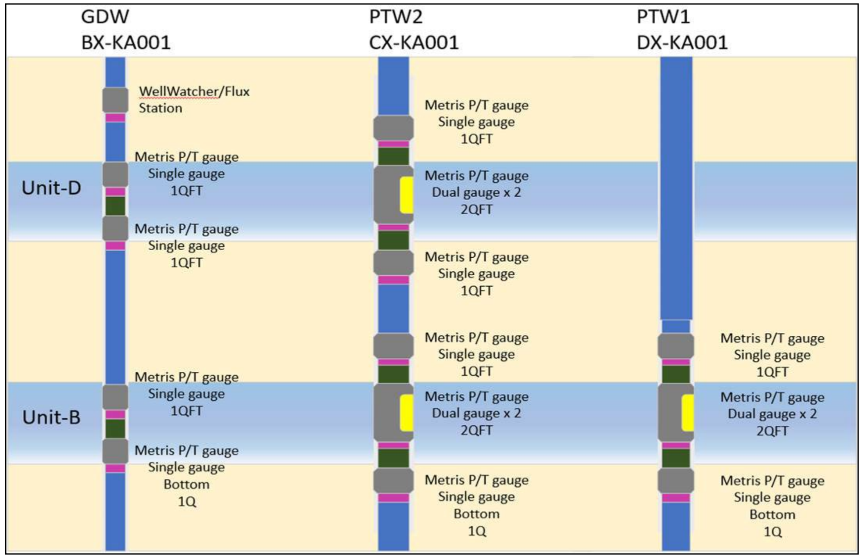
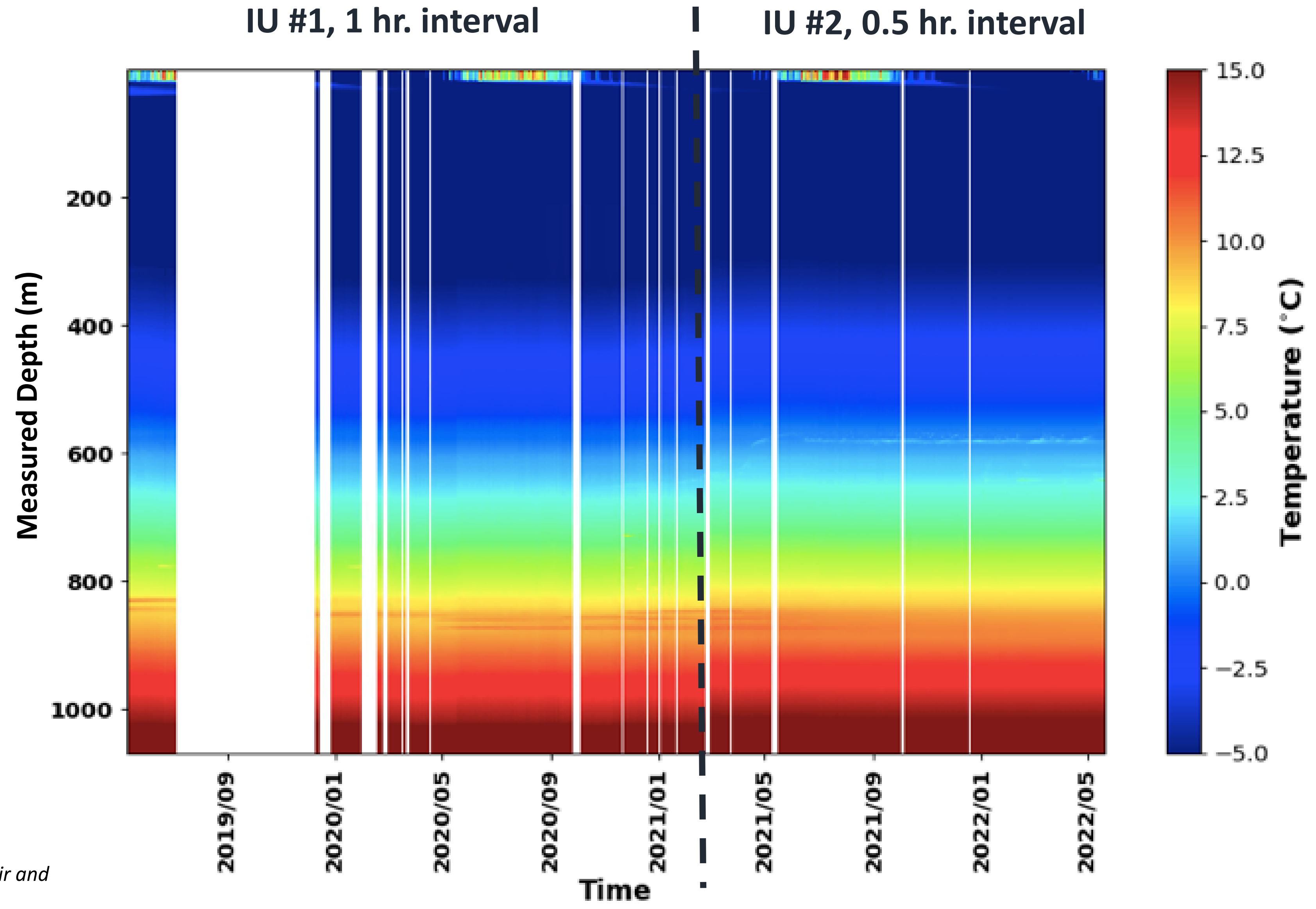
Gauge Systems
1Q = Single Port P/T gauge
2Q = Double Port P/T gauge
FT = Cable feed-through



Test Well Monitoring

Distributed Temperature System (DTS) – Hydrate 01 STW

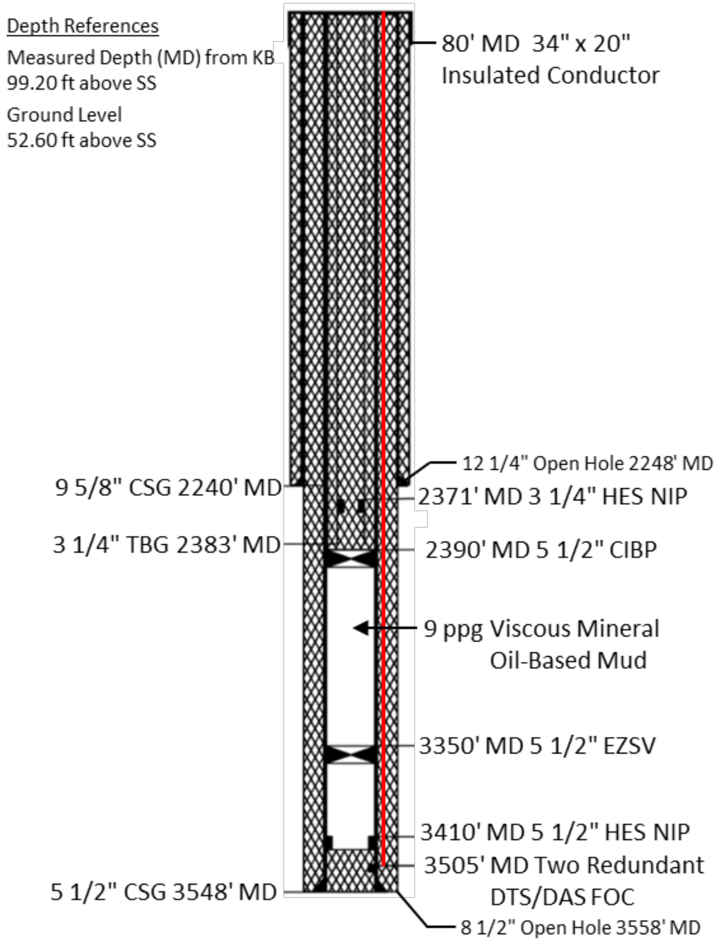
- Hydrate-01 STW cemented & abandoned on 01/28/2019
- DTS data collection period: May 2019 - May 2022
- Maximum measured depth 1069 m
- Double ended configuration
- 2 interrogators
- Sampling interval changed from 1 hr. to 0.5 hr. after February 21, 2021

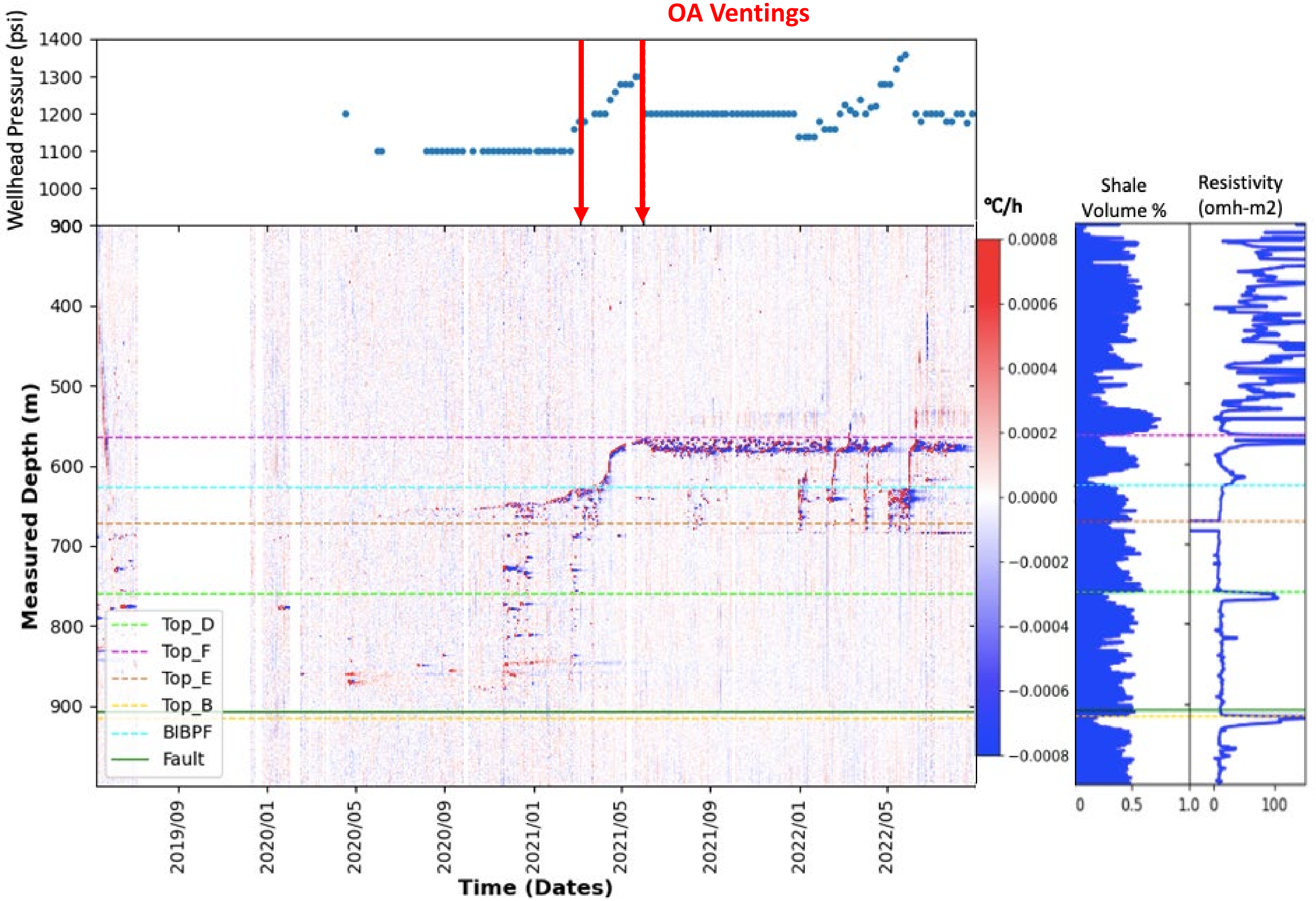


***Ana Garcia-Ceballos* – Colorado School of Mines**
SPE Workshop: Fiber-Optic Sensing Applications for Well, Reservoir and Asset Management; 8 - 9 Aug 2023 Westminster, Colorado, USA

Alaska Permafrost and Gas Hydrate Well Integrity Studies

Hydrate – 01
Stratigraphic Test Well
API No. 50029236130000

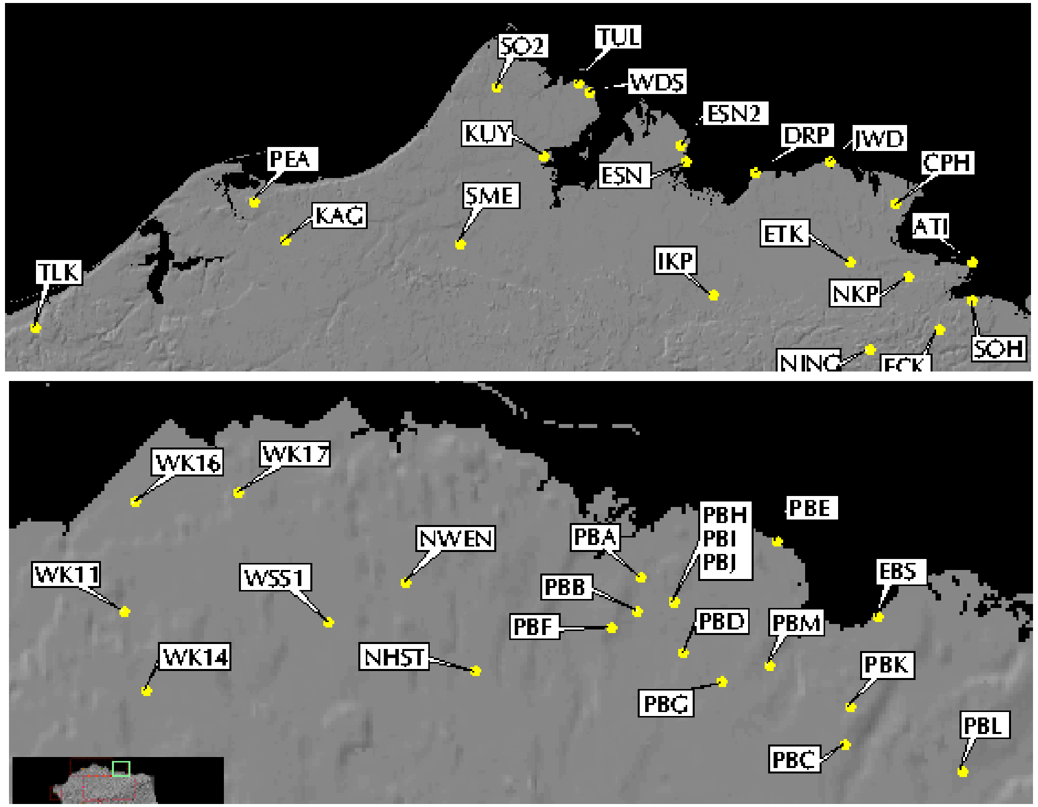


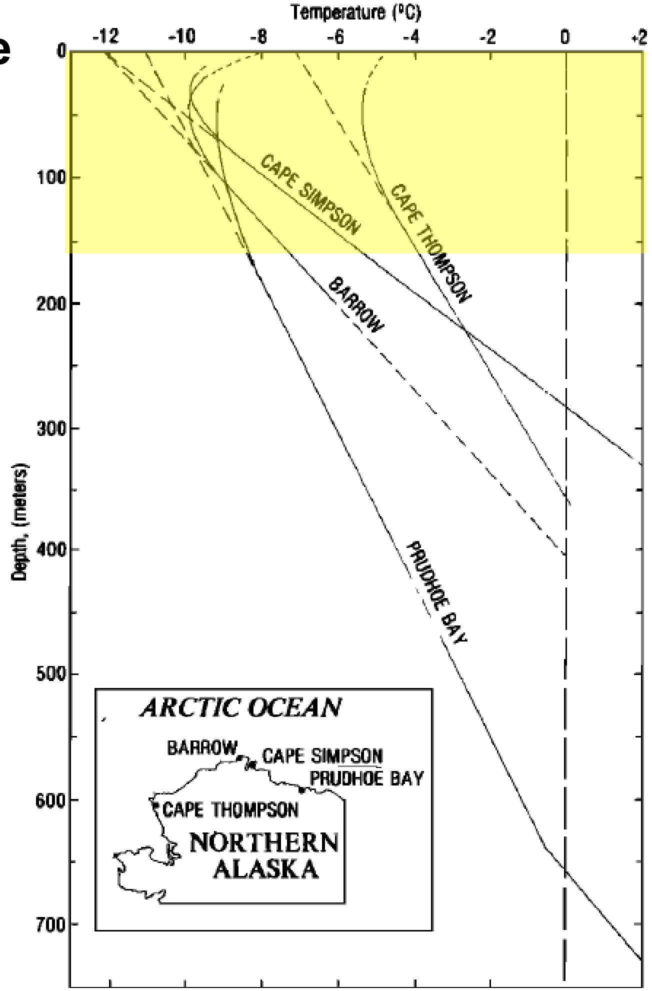


Hydrate-01 Waterfall DTS (temperature) display showing temperature changes over time with the graph at the top indicating outer annulus (OA) wellhead pressures and gas bleeding events where the OA pressure was vented.

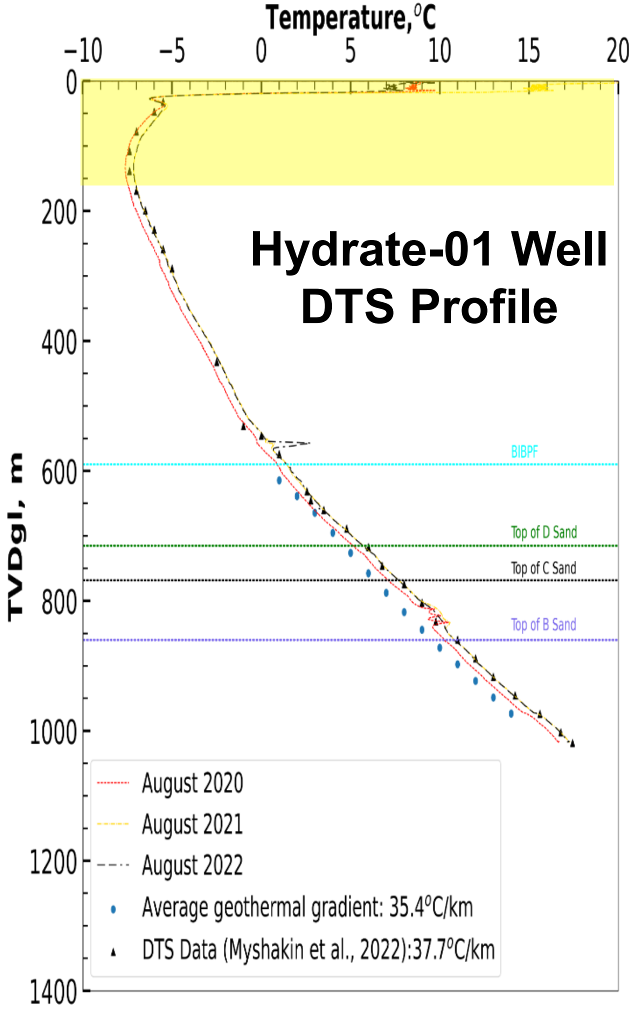
Alaska Permafrost and Gas Hydrate Thermal Regime

U.S. Geological Survey Borehole Temperature Surveys, North Slope Alaska, pre-1989





Lachenbruch et al., (1982) - USGS



Trend to warmer surface temperatures during the last century, same trend is seen in the Hydrat-01 well drilled and instrumented for continuous temperature and acoustic FO measurement since December of 2018.

Production Test Data Acquisition and Analysis

Gas Hydrate Production Sampling Program

USGS - Integrated analysis of downhole log, core, geophysical and production testing data.

Sample Type	Sample Frequency and Quantity	Recipients
(1) Produced Gas (USGS) - Daily	One daily (See: Section 3.1.3 Produced Gas USGS - Daily)	USGS
(2a) Produced Water (USGS) – Daily	One daily (See: Section 3.1.4 Produced Water USGS - Daily)	USGS
(2b) Produced Water (USGS) – Daily Reference	Every three days until production stabilizes, every seven days thereafter (See: Section 3.1.4 Produced Water USGS - Daily)	USGS
(3a) Produced Water (USGS) – Organics & Microbio	On request (See: Section 3.1.5 Produced Water USGS – Organics & Microbio)	USGS
(3b) Produced Water (USGS) – Organics & Microbio Reference	On request, once during the initial depressurization phase and once while the production rate is still low enough that fluids are being injected to support the downhole pumps (See: Section 3.1.5 Produced Water USGS – Organics & Microbio)	USGS
(4) Produced Solids (USGS)	On request (Section 3.1.6 Produced Solids USGS)	USGS

Plans for Ongoing & Future Testing

Alaska Gas Hydrate Production Field Experiment: Operation and Science

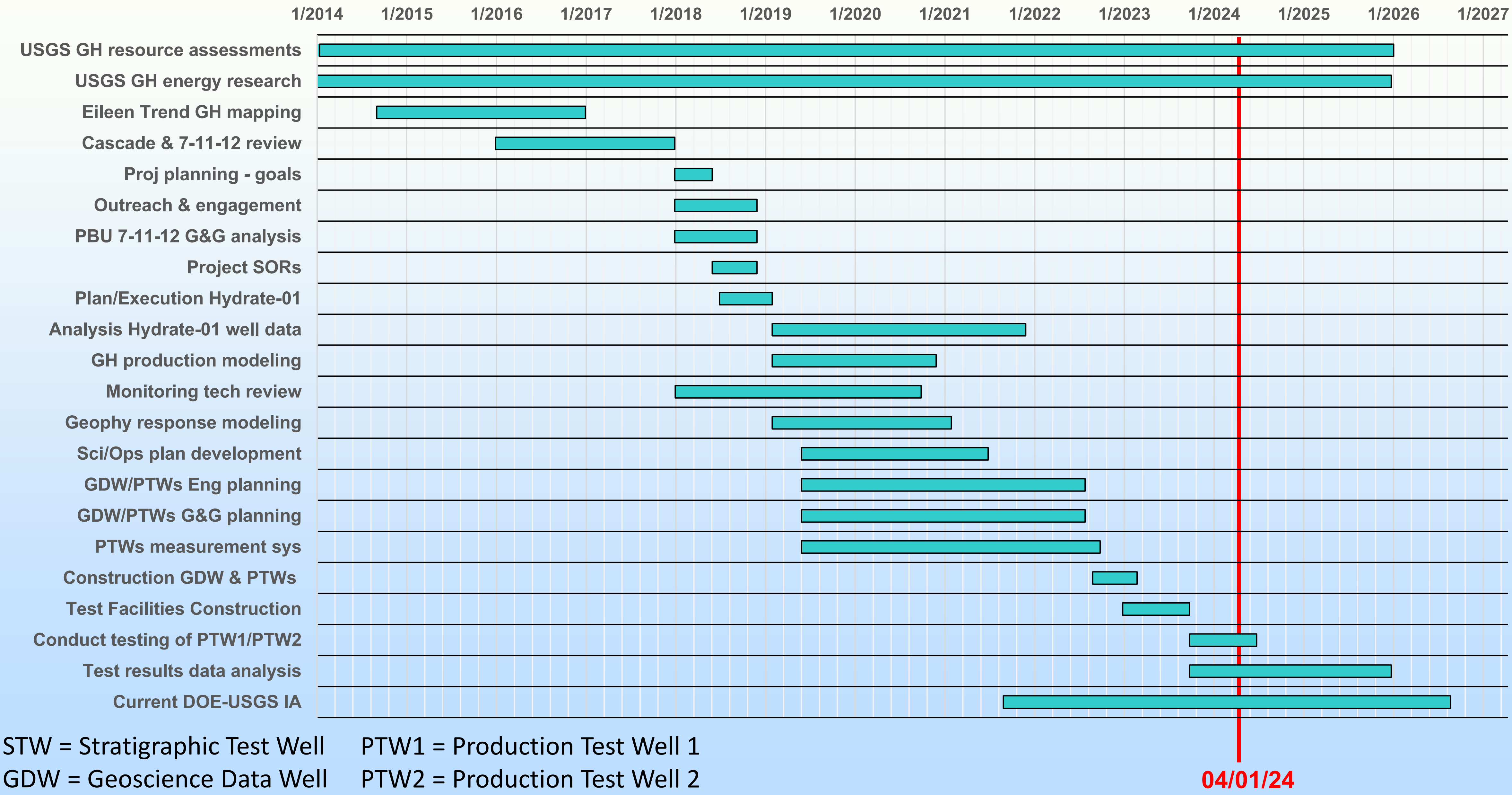
5. Project Data Analysis Plan

1. Field operational, production, geologic, geophysical data integration
2. Field and post-field core lab data analysis and integration
3. Partner core lab data analysis and integration
4. Contractor core lab data analysis and integration
5. Well log data integration and analysis
6. Geophysical data integration and analysis
7. Production and monitoring data integration and analysis
8. Operational Review - Well and test design
9. Operational Review - Surface and test facilities
10. Gas hydrate production forecasting and history matching
11. Geomechanical data analysis and integration with production testing data
12. Energy balance - Design of next stage stimulation to maximize gas rates

USGS will support DOE-led gas hydrate production modeling efforts, including the preparation of reservoir model input from available production data, and contribute to DOE led gas hydrate production modeling calibration studies.

Project Summary

ANS GH Testing - Gantt Chart



STW = Stratigraphic Test Well

GDW = Geoscience Data Well

PTW1 = Production Test Well 1

PTW2 = Production Test Well 2

USGS Gas Hydrate Project

USGS Energy Resources Program

U.S. Geological Survey
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CERSC Gas Hydrate Project Website