# EMD Gas Hydrates Committee
# Annual Report

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## Executive Summary

Global research on the potential commercial viability of gas extraction from gas hydrates is continuing, predominantly in Asia and in the United States. Recent research efforts have focused on the exploration and characterization of gas hydrate petroleum systems and conducting controlled short-term production tests of gas hydrate deposits hosted in sand-rich reservoirs.

During the past four years, a number of significant gas hydrate test wells have been completed. In 2017, gas hydrate production testing was conducted offshore Japan and China. In 2020, an additional test was conducted in the Shenhu region of the South China Sea in order to evaluate the effectiveness of various gas hydrate production well completion technologies. Late in 2018, a research partnership led by the U.S. Department of Energy National Energy Technology Laboratory (DOE-NETL) and the Japan Oil, Gas and Metals National Corporation (JOGMEC) established a new Alaska North Slope test site for an extended gas hydrate production pilot through the completion of the Prudhoe Bay Unit Hydrate-01 stratigraphic test well. This well verified the presence of sand-rich gas hydrate accumulations and will be used as a monitoring well for future production testing. Planning is underway for the drilling of three additional wells at the Alaska test site, which will include a geoscience data well and two production test wells. In 2018, the University of Texas at Austin released a comprehensive report describing the operational and initial technical results of the UT-GOM2-1 Hydrate Pressure Coring Expedition, which drilled and partially cored two wells in Green Canyon Block 955 in the deepwater Gulf of Mexico. In 2019, the Government of India released the results of one of the most comprehensive gas hydrate scientific drilling investigations ever undertaken. The leadership of the Indian National Gas Hydrate Program Expedition 02 reported the discovery of several significant gas hydrate accumulations that were assessed to be suitable for future gas hydrate production testing. In September 2019, the U.S. Geological Survey released a new assessment of the technically recoverable gas hydrate resources for the Alaska North Slope. The results of these recently completed wells, tests, and studies are reviewed in this American Association of Petroleum Geologists-Energy and Minerals Division Gas Hydrate Committee report.

## Status of U.S. Gas Hydrate Activities

### *Alaska North Slope Gas Hydrate Resource Assessment*

In 2018, the U.S. Geological Survey (USGS) completed a reassessment of the technically recoverable gas hydrate resources on the Alaska North Slope (ANS) (Collett et al., 2019a); the first assessment was completed in 2008 (Collett et al., 2008; U.S. Geological Survey Alaska Gas Hydrate Assessment Team, 2013). Both the 2008 and 2018 assessments used the geology-based, USGS methodology developed to assess conventional oil and gas resources. The Northern Alaska Gas Hydrate Total Petroleum System includes Cretaceous and Tertiary reservoir rocks divided into three Assessment Units (AUs), listed from oldest to youngest: the Nanushuk Formation Gas Hydrate AU, the Tuluvak-Schrader Bluff-Prince Creek Formations Gas Hydrate AU, and the Sagavanirktok Formation Gas Hydrate AU. Two of the critical components of the USGS assessment procedure are the accurate prediction of the expected size and number of undiscovered hydrocarbon accumulations within each of the delineated AUs. The 2018

assessment relied heavily on the analysis of industry-acquired 3D seismic data to characterize the size, number, and distribution of gas hydrate accumulations in each of the three assessed AUs (Figure 1). USGS scientists used seismic attribute analysis techniques to identify 103 seismically inferred gas hydrate accumulations throughout the Northern Alaska Gas Hydrate Total Petroleum System. These seismic inferred gas hydrate accumulations were used in this assessment to estimate the size and number of gas hydrate accumulations in each AU. Based upon limited field testing and gas-hydrate numerical production modelling of gas hydrate accumulations on the ANS, the assessment concluded that sand-rich hydrate reservoirs within the AUs could be produced using existing conventional technology.

Released on 10-September-2019, the assessment estimated a mean total volume of gas for the three gas hydrate AUs of 53,796 billion cubic feet (BCFG, recoverable) (Collett et al., 2019a), a significant decrease from the 85,427 BCFG reported in the 2008 USGS assessment (Collett et al., 2008; U.S. Geological Survey Alaska Gas Hydrate Assessment Team, 2013). This reduction is attributed to a more comprehensive prospect review process in the 2019 assessment due to the availability of additional 3D seismic data volumes and well-log datasets, which also allowed for improved mapping of all three AUs. The Tuluvak-Schrader Bluff-Prince Creek Formations and Nanushuk Formation Gas Hydrate AUs were determined to be smaller resulting in the reduction of the number of estimated gas hydrate accumulations in both AUs.

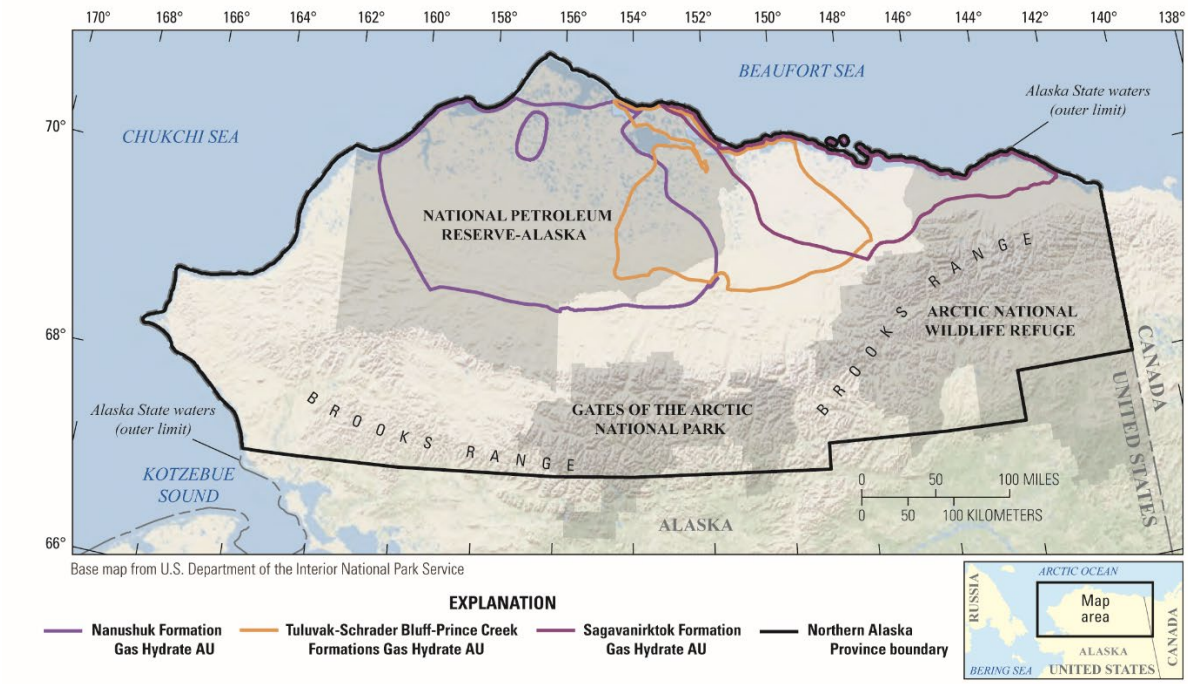


*Figure 1. Map of the Northern Alaska Province, showing boundaries of the three gas hydrate assessment units (AUs). Adjacent lines illustrate a shared boundary at the outermost line.*

***Alaska North Slope Gas Hydrate Production Studies***

The Eileen Gas Hydrate Trend along the western margin of the Prudhoe Bay Unit (PBU) on the ANS is one of the most extensively studied gas hydrate accumulations in the world. It has been the target of three gas hydrate scientific field stratigraphic and production testing programs, including the Mount Elbert (Boswell et al., 2011), Iġnik Sikumi (Schoderbek et al., 2012, 2013; Boswell et al., 2017), and the Hydrate-01 (Boswell et al., 2019a; Collett et al., 2019b; Okinaka et al., 2019) test well projects.

The Hydrate-01 well was drilled in 2018 as a stratigraphic test well on an established gravel pad in the western portion of the PBU as part of a project to conduct the world's first extended gas hydrate production test (Figure 2). This project is led by the U.S. DOE-NETL, JOGMEC, and the USGS, and includes the drilling of a geoscience data well and two production test wells. The ultimate goal of this project is to conduct a long-term (12-24 months) gas hydrate production test.

The Hydrate-01 well met all project objectives and confirmed the occurrence of highly saturated gas hydrate-bearing reservoirs (Boswell et al., 2019a) in the identified Unit B and Unit D Eileen trend stratigraphic units. Unit B, the deeper of the two reservoirs, comprises well-sorted, very fine-grained sand to coarse silts. The hydrate was interpreted to be filling 65 percent to more than 80 percent of the porosity in the upper 40 feet of Unit B. Unit D, the shallower of the two reservoirs, exhibits similar gas hydrate saturations to that observed for Unit B. With the success of the Hydrate-01 stratigraphic test well, the project leadership group is developing plans to drill a geologic data well and a production test well (Okinaka et al., 2019).

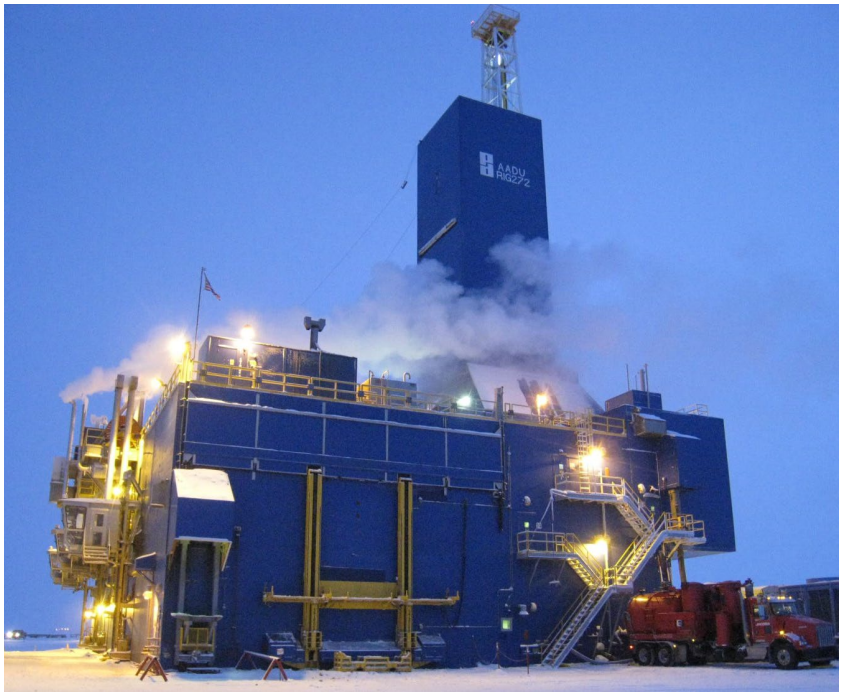


*Figure 2. The Parker 272 rig on location at the Hydrate-01 Stratigraphic Test Well, Prudhoe Bay Unit, Alaska, December 2018.*

### *UT-GOM2-1: Gulf of Mexico Hydrate Pressure Coring Expedition*

From 2-May-2017 to 22-May-2017, the UT-GOM2-1 Hydrate Pressure Coring Expedition drilled two wells in Green Canyon Block 955 (GC 955) in the deepwater Gulf of Mexico: Hole GC 955 H002 (H002) and Hole GC 955 H005 (H005) (Flemings et al., 2018). A total of 21 pressure cores (10 ft; 3.05 m in length) were attempted in and near the gas hydrate reservoir section previously drilled and logged in 2008 (Boswell et al., 2012). In the first hole, H002, only one of eight cores were recovered under pressure and there was 34% recovery of sediment (both pressurized and depressurized cores). In the second hole, H005, a total of 12 of 13 attempted cores were recovered under pressure and sediment recovery was 72%. The pressure cores were X-ray imaged and logged under pressure. Samples were quantitatively degassed either onboard or onshore to determine the hydrate concentration and the gas composition. Pore water analyses were performed on depressurized samples, and sediment samples were collected to enable characterization of the microbial composition of the recovered sediment cores. A total of 21 (3.3 ft; 1 m in length) vessels containing pressure core sections were returned to the University of Texas for storage, distribution, and further analysis. The scientific results of UT-GOM2-1 Hydrate Pressure Coring Expedition is planned for publication as a special issue of the American Association of Petroleum Geologists later in 2020.

## Status of International Gas Hydrate Activities

### *Nankai Trough (Japan)*

In 2013, the Methane Hydrate 2001 Consortium (also known as MH21) completed the first ever test of gas production from marine gas hydrates (Yamamoto, 2015; Konno et al., 2017). The drilling vessel *D/V Chikyu*, was used for drilling and coring operations to establish the MH21 Nankai Trough 2012-2013 test site (ATI). The AT1 gas hydrate production test started on 12-March-2013 and was terminated on 19-March-2013, which was earlier than originally planned, due to sand production problems and deteriorating weather conditions. The cumulative volume of gas and water produced during the 6-day test at AT1 was estimated at ~120,00 $m^3$ and ~1,300 $m^3$, respectively (Yamamoto, 2015; Konno et al., 2017).

Based on the results of the 2013 AT1 test, a second test at the same site was designed and executed in 2017 to acquire additional quantitative data for the assessment of various gas hydrate production completion technologies. In June 2017, the Japan Agency for Natural Resources and Energy conducted a new production test in the Nankai Trough, as commissioned by JOGMEC, to test gas hydrate production in the offshore area between the Atsumi and Shima Peninsulas (Daini Atsumi Knoll). This new field trial tested completion technologies designed to deal with the sand production issues experienced in the first Nankai Trough production test in 2013 (Yamamoto et al., 2019). Sand was again produced in the first 2017 well and the test was terminating after about 12 days. The second 2017 well produced no sand across the completion and was operated for 24 days and produced 222,600 $m^3$ of gas at rates of approximately 10,000 $m^3$ per day. The wells showed different production behavior, with increased water production ratios in the second well related to complex lateral heterogeneities in the reservoir as reported in Yamamoto et al. (2019).

***South China Sea (China)***

The Guangzhou Center for Gas Hydrate Research was established in 2004 to conduct energy focused laboratory and field studies of gas hydrate systems offshore China. In May and June of 2017, the China Geological Survey conducted an "industrial pilot" gas hydrate production test in the Shenhu area (Li et al., 2018). The water depth at the test site was at 1,266 m, and the hydrate-bearing reservoir section was at a depth of 203-277 m below the seabed. Core data from the location confirmed that the hydrate was in a pore-filling mode with gas hydrate saturations commonly ranging from 30 to 60 percent. The lower observed saturations are attributed to the presence of lower reservoir quality clay-rich silts and silty clays. The Shenhu production test was conducted for 60 days with total cumulative gas production of 309,000 $m^3$ (Li et al., 2018). An aspect of the accumulation that likely contributed to the significant volume of produced gas was the presence of free gas below and interbedded with the gas hydrate, reflective of the possible thermogenic origin of the gas, and the occurrence of both Structure I and Structure II gas hydrates (Qian et al., 2018).

The China Geological Survey, under the direction of the Ministry of Natural Resources, and more than 70 other entities, including China National Petroleum Corporation conducted a second gas hydrate test offshore China in October of 2019. On 19-March-2020, the China Ministry of Natural Resources reported that they had conducted the second gas hydrate production test in the South China Sea. The test well was located in the Shenhu area at a water depth of 1,225 m, and the test well extracted a total of 861,400 $m^3$ of gas over a period of 31 days, with a reported average daily production rate of about 28,700 $m^3$ (https://www.scmp.com/print/news/china/society/article/3077156/china-extracts-861400-cubic-metres-natural-gas-flammable-ice).

***Bay of Bengal (India)***

The scientific results of the Indian National Gas Hydrate Program Expedition 02 (NGHP-02) were published in October of 2019 as a special issue of the Journal of Marine and Petroleum Geology (2019; Volume 108; https://www.sciencedirect.com/journal/marine-and-petroleum-geology/vol/108/suppl/C). This special issue contains four reports that summarize the information contained within the 41 technical reports that detail the operational and scientific results of the NGHP-02 Expedition. The first summary report, "India National Gas Hydrate Program Expedition 02: Operational and Technical Summary," focuses on reviewing the tools and operational procedures for the NGHP-02 Expedition. The expedition acquired an unprecedented amount of high-quality downhole log and core data from numerous pore-filling, fracture-filling, and sediment-displacement types of gas hydrate occurrences (Kumar et al., 2019). The Open-Access summary report titled "India National Gas Hydrate Program Expedition 02 Summary of Scientific Results: Gas Hydrate Systems Along the Eastern Continental Margin of India" documents gas hydrate occurrences discovered during the NGHP-02 Expedition and examines geologic controls on the gas hydrate systems along the eastern continental margin of India (Collett et al., 2019c). The "India National Gas Hydrate Program Expedition 02 Summary of Scientific Results: Evaluation of Natural Gas Hydrate-Bearing Pressure Cores" summary report presents a systematic review of select findings and implications

of the coordinated pressure-core evaluation program as described in numerous technical reports within this special issue (Boswell et al., 2019b). The summary report titled "India National Gas Hydrate Program Expedition 02 Summary of Scientific Results: Numerical Simulation of Reservoir Response to Depressurization" addresses the key issues associated with understanding the potential production response of two gas hydrate accumulations discovered during the NGHP-02 Expedition to scientific depressurization experiments (Boswell et al., 2019c).

It has been shown that the formation of highly concentrated gas hydrate accumulations, which are more suitable for energy extraction, requires the presence of relatively coarse-grained sediments with porosity sufficient to support the migration and accumulation of gas and the nucleation of gas hydrate (Yamamoto et al., 2019). The results of downhole logging, coring, and formation pressure testing operations during NGHP-02 have confirmed the presence of extensive sand-rich depositional systems throughout the deepwater portions of the Krishna-Godavari and Mahanadi Basins (Figure 3; Collett et al., 2019c). Two areas of the Krishna-Godavari Basin, referred to as Areas B and C, contain substantial gas hydrate accumulations in sand-rich systems and therefore represent excellent candidate sites for future gas hydrate production testing.

In the Krishna-Godavari Basin, extensive reservoir systems were confirmed with sediment grain sizes ranging from coarse silts to gravels. These reservoirs were determined to be fully to partially filled with gas hydrate. The discovered gas hydrate accumulations were derived from microbial gas sources, with some of the gas migrating into the reservoirs from deeper systems. The gas hydrate petroleum systems identified in the basin are complex with substantial reservoir heterogeneity and sufficient permeability throughout the reservoirs and seals that allowed for pervasive fluid flow into and through the hydrate-bearing systems (Collett et al., 2019c). These discoveries were made with an innovative exploration approach that focused on the seismic detection of hydrate reservoirs and comprehensive petroleum systems analyses.

The work conducted on the NGHP-02 cores reinforced insights from prior work, including the strong correlations between the nature of the sediment (grain size, sorting, mineralogy), gas hydrate saturation, and sediment strength properties (Boswell et al., 2019b). These studies also confirmed other recent findings regarding the variability in gas hydrate reservoir quality, most notably the occurrence of permeabilities of tens of milli-Darcys within highly saturated core samples. The core studies also provided insight into the potential impacts of post-depressurization reservoir consolidation on reservoir effective permeabilities.

To assess the potential response of discovered gas hydrate deposits to depressurization, comprehensive geologic models were constructed to enable numerical simulation of expected gas hydrate production from two sites (Boswell et al., 2019c). Both sites (Area C: NGHP-02-09 and Area B: NGHP-02-16) feature thick sequences of thinly interbedded reservoir and non-reservoir facies at sub-seafloor depths less than 300 m and sub-sea depths of 2,900 m or more. These settings pose significant challenges to current modeling capabilities. First, the thinly interbedded reservoir architecture complicates the determination of basic reservoir parameters from both log and core data due to measurement resolution issues. Second, the fine-scale variation in sediment properties imparts great contrasts in key parameters over very short distances, creating high gradients at multiple scales and varying orientations that necessitate careful design of high-definition simulation grids. Third, the deposits include internal sources of

water, as well as a range of complex boundary conditions, including variable permeability within the overlying mud-rich "seals" that complicate reservoir depressurization. Together, these concerns confirm the viability of the modeled accumulations for scientific testing and identify key challenges related to the selection of specific test sites and the design of test wells.

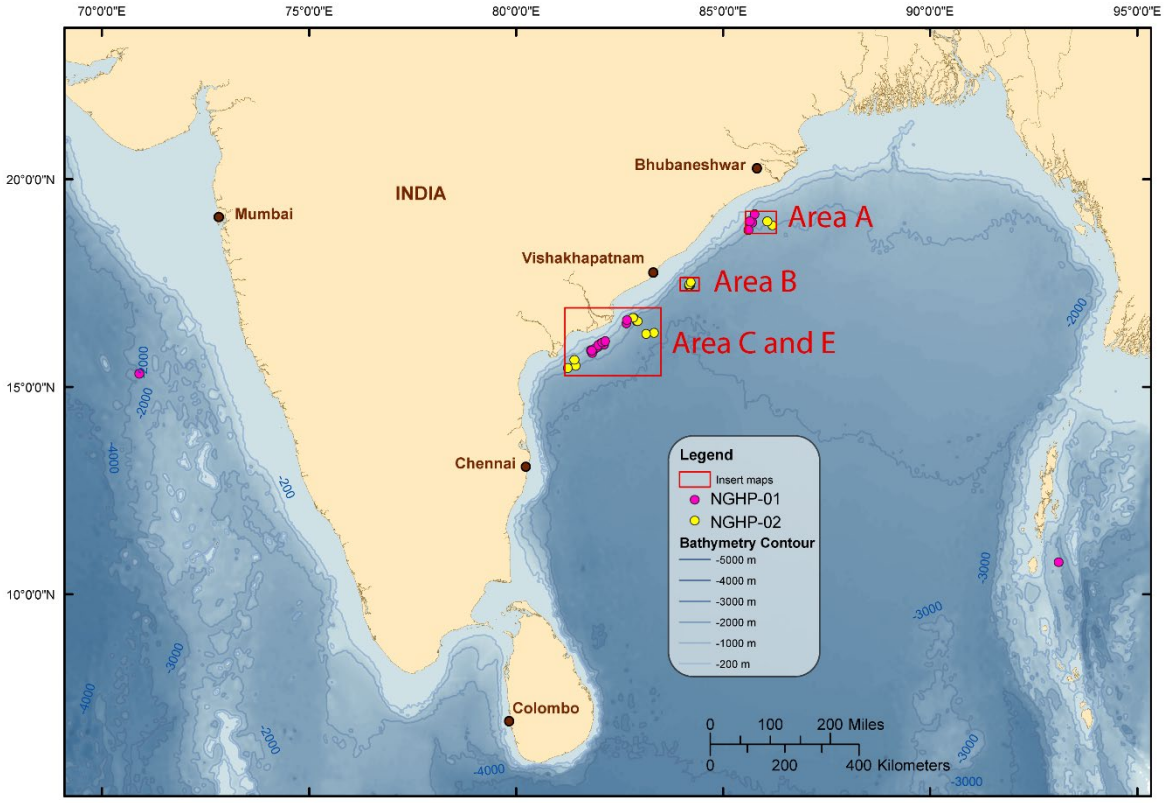


*Figure 3. National Gas Hydrate Program Expedition 01 (NGHP-01) and National Gas Hydrate Program Expedition 02 (NGHP-02) drill site map depicting the location of the drill sites established during both expeditions in the Krishna-Godavari (Area B, Area C and Area E), Mahanadi (Area A), Kerala-Konkan (west coast of India) and in the Andaman (western edge of the Andaman Sea) deep offshore areas of India.*

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