U.S. DEPARTMENT OF ENERGY

Fiscal Year 2019 Gas Hydrates R&D Program

Report to Congress
September 2020

United States Department of Energy
Washington, DC 20585

Message from the Secretary

The U.S. Department of Energy (DOE) is required to send to Congress an annual report on the actions taken to carry out gas hydrate research and development.[1]

I am pleased to provide the *Fiscal Year 2019 Methane Hydrate Program*. DOE's Office of Fossil Energy (FE) prepared this report summarizing the progress made in this area of research.

DOE is providing this report to:

- **The Honorable Michael R. Pence**
  President of the Senate

- **The Honorable Nancy Pelosi**
  Speaker of the House of Representatives

- **The Honorable Lisa Murkowski**
  Chairman, Senate Committee on Energy and Natural Resources

- **The Honorable Joe Manchin**
  Ranking Member, Senate Committee on Energy and Natural Resources

- **The Honorable Eddie Bernice Johnson**
  Chairwoman, House Committee on Science, Space and Technology

- **The Honorable Frank Lucas**
  Ranking Member, House Committee on Science, Space and Technology

- **The Honorable Frank Pallone**
  Chairman, House Committee on Energy and Commerce

- **The Honorable Greg Walden**
  Ranking Member, House Committee on Energy and Commerce

- **The Honorable Richard Shelby**
  Chairman, Senate Committee on Appropriations

- **The Honorable Patrick Leahy**
  Vice Chairman, Senate Committee on Appropriations
- **The Honorable Nita Lowey**
  Chairwoman, House Committee on Appropriations

[1] 30 U.S.C. § 2003(e)(5).

- **The Honorable Kay Granger**
  Ranking Member, House Committee on Appropriations

- **The Honorable Lamar Alexander**
  Chairman, Senate Subcommittee on Energy and Water Development
  Committee on Appropriations

- **The Honorable Dianne Feinstein**
  Ranking Member, Senate Subcommittee on Energy and Water Development
  Committee on Appropriations

- **The Honorable Marcy Kaptur**
  Chairwoman, House Subcommittee on Energy and
  Water Development and Related Agencies
  Committee on Appropriations

- **The Honorable Mike Simpson**
  Ranking Member, House Subcommittee on Energy and
  Water Development and Related Agencies
  Committee on Appropriations

If you have any questions or need additional information, please contact me or, Ms. Katie Donley Associate Director for External Coordination, Office of the Chief Financial Officer, at (202) 586-0176; Mr. Christopher Morris, Deputy Assistant Secretary for House Affairs, or Mr. Shawn Affolter, Deputy Assistant Secretary for Senate Affairs, Office of Congressional and Intergovernmental Affairs, at (202) 586-5450.

Sincerely,

Dan Brouillette

Executive Summary

The Methane Hydrate Research and Development Act of 2000, as amended by Section 968 of the Energy Policy Act of 2005, directs the Secretary of Energy to annually send a report to Congress on the actions taken for the Gas Hydrate Research and Development (R&D) program.[2] This report fulfills that requirement for fiscal year 2019. It summarizes the program's activities and accomplishments, including the publication of 30 peer-reviewed papers.

The Office of Oil and Natural Gas within the Office of Fossil Energy (FE) manages the Gas Hydrate R&D program with support from the National Energy Technology Laboratory (NETL). The program's research is conducted by NETL with partners in industry, academia, states, and Federal agencies. As in prior years, the fundamental goal of the program is to expand the understanding of the nature of gas hydrate systems and the energy resource potential of gas hydrates for the United States and the world.

In 2019, DOE allocated $20 million to the Gas Hydrates R&D program per Congressional direction. With this funding, the program continued its primary ongoing efforts, focused on:

- Development of a long-term reservoir response experiment on the Alaska North Slope in partnership with Japan, private industry, the U.S. Geological Survey, and the Alaska Department of Natural Resources.
- Evaluation of pressurized core samples acquired from Gulf of Mexico gas hydrate reservoirs in previous years and preparation for further deepwater characterization and pressure core sampling in the Gulf of Mexico.
- Collaboration with ongoing international programs, most notably with partners in India, Japan, and South Korea.

Gas hydrate is a cage-like lattice of ice that contains trapped molecules of methane, the chief constituent of natural gas. If a gas hydrate is warmed or depressurized, water and natural gas are released. Gas hydrates are a potentially huge future source of natural gas, with global resources estimated to range from 250,000–700,000 trillion cubic feet (tcf).

Building on the Department of Energy's (DOE) Gas Hydrates R&D program work, assessments from the U.S. Department of Interior (DOI) concluded that 50 tcf of U.S. gas hydrate resources are available in Alaska and thousands of tcf are available offshore, compared to the 2,828.8 tcf of technically recoverable resources of dry natural gas. In limited settings, it has been shown that natural gas within hydrates is technically recoverable; however, it has yet to be proven that this gas can be produced on a scale and at a cost suitable for commercial production.

The Gas Hydrates R&D program is working to address the challenges assessing the location and amount of the hydrate resource and determining the best way to extract the gas from hydrates through early-stage R&D. The program is: 1) gathering technical data to confirm DOI resource

[2] 30 U.S.C. § 2003(e)(5).

characterizations for offshore hydrate deposits; 2) assessing the potential commercial viability of gas production from hydrates through experimental field and lab work using Alaska's onshore hydrate deposits; and 3) advancing the United States' fundamental understanding of the nature and evolution of the geologic systems that produce, store, and sustain gas hydrate deposits.

FISCAL YEAR 2019 METHANE HYDRATE PROGRAM

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I. Legislative Language

This report describes actions taken in fiscal year (FY) 2019 to implement the Methane Hydrate Research and Development (R&D) Act of 2000, as amended by Section 968 of the Energy Policy Act of 2005. This Act directs the Secretary of Energy to annually send a report to Congress on the actions taken to carry out the program.

II. Summary of Accomplishments in FY 2019

In FY 2019, the program continued the advancement of gas hydrate science and technology through various U.S. Department of Energy (DOE) National Laboratory projects, interagency agreements, contracts, and cooperative agreements with the private sector (primarily with universities). The most significant events and activities during FY 2019 included:

- The successful drilling, logging, and sampling of gas hydrate reservoirs at the initial Stratigraphic Test Well (Hydrate-01), which confirmed the occurrence of an outstanding site for scientific reservoir response testing operations within the western Prudhoe Bay Unit, Alaska North Slope.
- The evaluation of Hydrate-01 data and the further refinement of plans for scientific testing at the established Alaska test site.
- The continued evaluation of samples collected during Expedition GOM2-1 in the Gulf of Mexico during FY 2017 and the development of project frameworks and scientific plans for a second drilling and coring program (GOM2-2).
- Collaborative study with 21 global research groups to compare and advance gas hydrate numerical simulation codes, with a focus on integration of gas hydrate dissociation and gas release with geomechanical phenomena.
- Collaborative study with researchers from the United States, India, Japan, and the United Kingdom to synthesize and publish the wide range of fundamental scientific and technical findings from the study of samples and data collected by India in the Bay of Bengal in FY 2015.

Sections of this report summarize key activities in FY 2019:

1. Gas Hydrate Reservoir Response Testing in Alaska

Field programs aimed toward production technology development and testing began in Alaska in FY 2004. In 2007, the “Mt. Elbert” test well, drilled in partnership with BP Exploration Alaska (BPXA) from a temporary ice pad in the Milne Point Unit (Figure 1), acquired the first physical samples and reservoir data on Alaska gas hydrates and demonstrated the ability to conduct research safely and non-disruptively within an area of ongoing industry operations. From 2008 to 2010, NETL developed a broader industry partnership toward potential long duration testing of both depressurization and chemical injection/exchange from an existing gravel pad in the

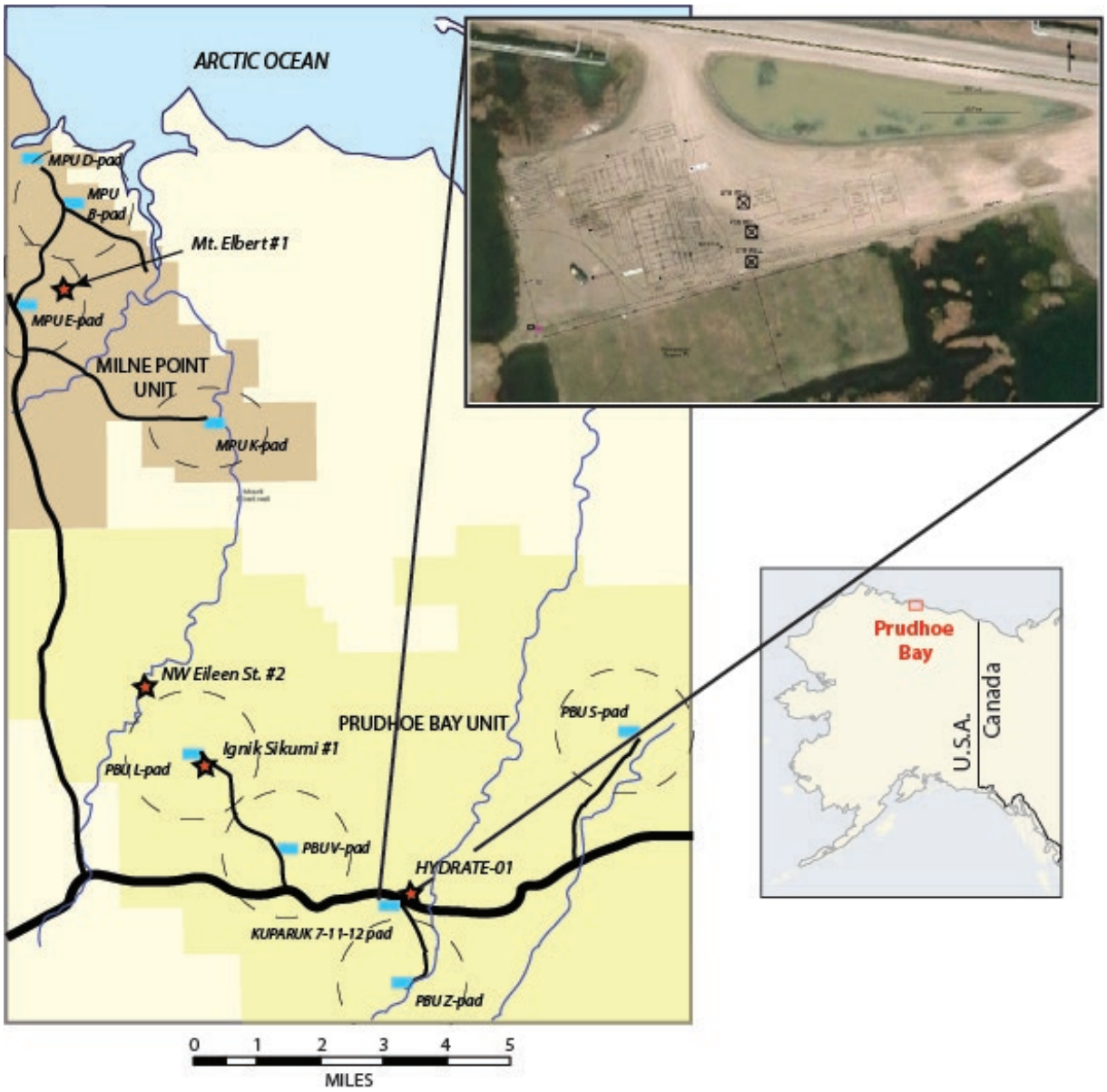

***Figure 1**: Location of prior gas hydrate field testing sites in the greater Prudhoe Bay Unit, Alaska North Slope. Top inset shows the "7-11-12" gravel pad adjacent and just south of the PBU Spine Road that was the selected site for FY 2019 stratigraphic test well drilling operations.*

western Prudhoe Bay Unit (PBU). Due to various site access limitations and other issues, those plans were modified for only short-duration exchange testing at the "Ignik Sikumi" well in partnership with ConocoPhillips and Japan in 2011 and 2012. In 2013, the Prudhoe Bay partners indicated that changing macroeconomic conditions warranted no compelling business case for the partners' continued collaborative gas hydrate R&D in Alaska. After recognizing the significant long-term value of the resource, the Alaska Department of Natural Resources (DNR) and DOE's Office of Fossil Energy signed a Memorandum of Understanding (MOU) to facilitate further gas hydrate field programs on the ANS in 2014. The Alaska DNR set aside tracts of unleased lands adjacent to the Milne Point and Prudhoe Bay Units so that DOE could determine if a feasible gas hydrate field experiment could be conducted there. In 2016, collaborative technical review between NETL, the

Japan Oil, Gas, and Metals National Corporation (JOGMEC), and the United States Geological Survey (USGS) concluded that the state lands sites were not conducive for long-term testing due to high costs and high risks, respectively, associated with lack of infrastructure (roads, pads, power, gas and liquid gathering lines, etc.) and an uncertain occurrence of gas hydrate. Consequently, the project team, with DNR support, re-engaged the PBU partners in search of viable locations within the Unit where a scientific testing program could be conducted with minimal impact on ongoing commercial, conventional operations within that Unit. In FY 2017, a promising site ("7-11-12 pad") was identified. This site targeted the structurally highest and least geologically complex location within the inferred hydrate occurrence that was sufficiently offset from the pre-existing wellbores. This site retained significant geological uncertainty. Therefore, a plan was developed to drill Hydrate-01, an initial Stratigraphic Test Well, to confirm the suitability of the location (See Appendix A1). If successful, that well would be converted to a monitoring well with the intent of then drilling two production test wells and an additional data collection/monitoring well.

In the first quarter of 2019, Hydrate-01 was spud by BPXA on December 10, 2018 (Figure 2). Due to careful control of drilling rates, the use of chillable oil-based mud, and the careful attention to mud temperature maintenance, the main portion of the well was in very good condition, resulting in outstanding quality logging-while-drilling (LWD) data. To gather grain size and other data needed to inform the design of the production test well, sidewall pressure cores were collected (Figure 3). The well results confirmed the occurrence of two high-quality reservoirs fully saturated with gas hydrate and in ideal condition for the desired long-term testing (see Appendix A2). Upon observing the success of the well, fiber-optic cables were installed prior to well abandonment to use the Hydrate-01 as a monitoring well for future testing operations (Figure 3). Later in FY 2019, JOGMEC acquired a large-scale distributed acoustic sensing vertical-seismic profile dataset utilizing the Hydrate-01 cables. Throughout the remainder of FY 2019, U.S. and Japanese scientists continued to evaluate the samples and data in support of numerical simulations and design of future testing and monitoring wells.

***Figure 2**: The Parker 272 rig on location at the 7-11-12 site, Prudhoe Bay Unit, December 2018. The well was operated by BP Exploration, (Alaska), Inc. with NETL's contractor Petrotechnical Resources-Alaska.*

***Figure 3**: Operations at the Hydrate-01 well included side-wall pressure coring (left) and deployment of twin distributed acoustic sensing/distributed temperature sensing fiber-optic cables as strapped to the well casing during completion (right).*

The current interpretation of Hydrate-01 data indicates that the primary reservoir target ("Unit B") is well-sorted, very fine-grained sand to coarse-silts with gas hydrate saturation ranging from 65 percent to more than 80 percent in the upper 40-feet of the unit. Unit B occurs near the base of the gas hydrate stability zone at a temperature of at least 50° Fahrenheit (F) and contains no free-water leg at the well location and is therefore very well suited for scientific production testing. A secondary and shallower target ("Unit D") was also confirmed. This unit had a thickness and saturation similar to that of Unit B. Occurring at 40° F and with a water-bearing section at its base, Unit D could provide opportunities to investigate additional scientific and well design issues as a potential follow-on to testing in Unit B.

At the end of FY 2019, the partners continued to coordinate with the PBU companies and the State of Alaska to determine the most viable means to implement further testing plans at the site.

2. Characterization of U.S. Offshore Gas Hydrate Resources

A key goal of the program is to refine the knowledge of the scale and nature of the occurrence of gas hydrate on the U.S. Outer Continental Shelf (OCS). From 2001 to 2014, the flagship offshore project had been the Gas Hydrates Joint Industry Project (JIP). JIP was a cooperative research project between DOE (in coordination with the USGS and BOEM) and an international consortium of industry and academic partners under the leadership of Chevron. In 2005, JIP "Leg I" drilling delivered results that resolved the JIP's geohazard concerns regarding drilling through gas hydrates while exploring for deeper hydrocarbons. The "Leg II" drilling program in 2009 confirmed the occurrence of resource-quality gas hydrates in the Gulf of Mexico, validating an earlier DOI resource assessment in 2008, and establishing two high-value sites for future research. Global gas hydrate exploration and evaluation continue to rely heavily on the concepts of gas hydrate exploration developed within the JIP.

In FY 2015, NETL partnered with the University of Texas at Austin (UTA) to develop plans to further gas hydrate scientific exploratory drilling and to collect the first pressure-core samples from the previously discovered sites. In FY 2017, UTA expedition "GOM2-1" acquired extensive high-quality samples from a deposit in Green Canyon block 955. In FY 2019, laboratory studies of those samples continued at UTA (Figure 4) and were initiated at labs at NETL, USGS, and the National Institute of Advanced Industrial Science and Technology (AIST) in Japan. This collaborative program of laboratory studies focuses on assessing the in-situ petrophysical, geomechanical, and geochemical nature of deepwater marine gas hydrate-bearing sediments.

Figure 4: *UTA scientists monitoring the evaluation of pressurized gas hydrate-bearing sediment samples at the UTA pressure core laboratories in FY 2019.*

The UTA effort continues to plan for a second drilling and coring expedition ("GOM2-2") designed to address fundamental issues of gas hydrate formation and gas hydrate reservoir conditions by obtaining pressure cores from multiple zones and multiple sites at the Walker Ridge 313 accumulation. In FY 2019, ongoing efforts to realize significant cost efficiencies by conducting the program in collaboration with the Integrated Ocean Discovery Program (IODP) were finally abandoned when the European affiliate of the IODP declined the UTA drilling proposal. Planning during the remainder of FY 2019 focused on direct contracting of an industry drilling platform by UTA in a manner similar to that used in FY 2017. This approach results in higher costs for the vessel and as such, NETL, USGS, and UTA spent considerable effort evaluating reduced expedition programs that would maximize scientific value. Ultimately, it was determined that plans for new site exploration and for in-situ wireline pressure testing would need to be dropped from the program. At the end of FY 2019, the anticipated timeline for GOM2-2 drilling was set to FY 2022.

UTA and contractor Geotek continued to refine and test the pressure core with ball valve to address issues with delayed pressure sealing during core retrieval observed in GOM2-1. In FY 2019, initial bench-scale performance testing of the modified tool was conducted at simulated reservoir conditions at Geotek's facilities in Salt Lake City, UT (Figure 5). Additional bench-scale performance testing of the tool is slated for early FY 2020. A full-scale land test of the system will be performed in March 2020 at the Schlumberger Test Center in Cameron, Texas.

Figure 5: *Pressure coring tool bench testing operations conducted by UTA and Geotek in preparation for ultimate deployment during Gulf of Mexico Expedition GOM2-2.*

A series of scientific reports on the findings of the 2017 drilling program were published in FY 2019 (see Appendix B). These reports will be assembled into an initial Special Issue of the *Bulletin of the American Association of Petroleum Geologists* early in late June 2020. The papers outline the geology of the GC 955 site in unprecedented detail, discuss the detailed sedimentology of the host reservoirs; and the geochemistry of a potential source of gas recovered, and describe the function of the pressure core technology. A second Special Issue is slated to appear in FY 2021 that will report the findings of the ongoing microbiological, petrophysical, and geomechanical studies of the acquired pressure cores.

The University of California at San Diego's Scripps Institution of Oceanography completed its evaluation of 359 line-kilometers of controlled source electromagnetic (CSEM) data over the proposed GOM2-2 drill sites. The data showed increased resistivity in shallow zones that were shown to host modest amounts of fracture-filling hydrate during 2009 drilling (Figure 6). These accumulations are not evident in traditional seismic, suggesting that CSEM may be a valuable component of comprehensive evaluations of gas hydrate systems. However, the deeper and more concentrated reservoir-grade accumulations, which are well expressed in seismic data, are not well imaged in CSEM, likely due to issues of vertical resolution in the CSEM data.

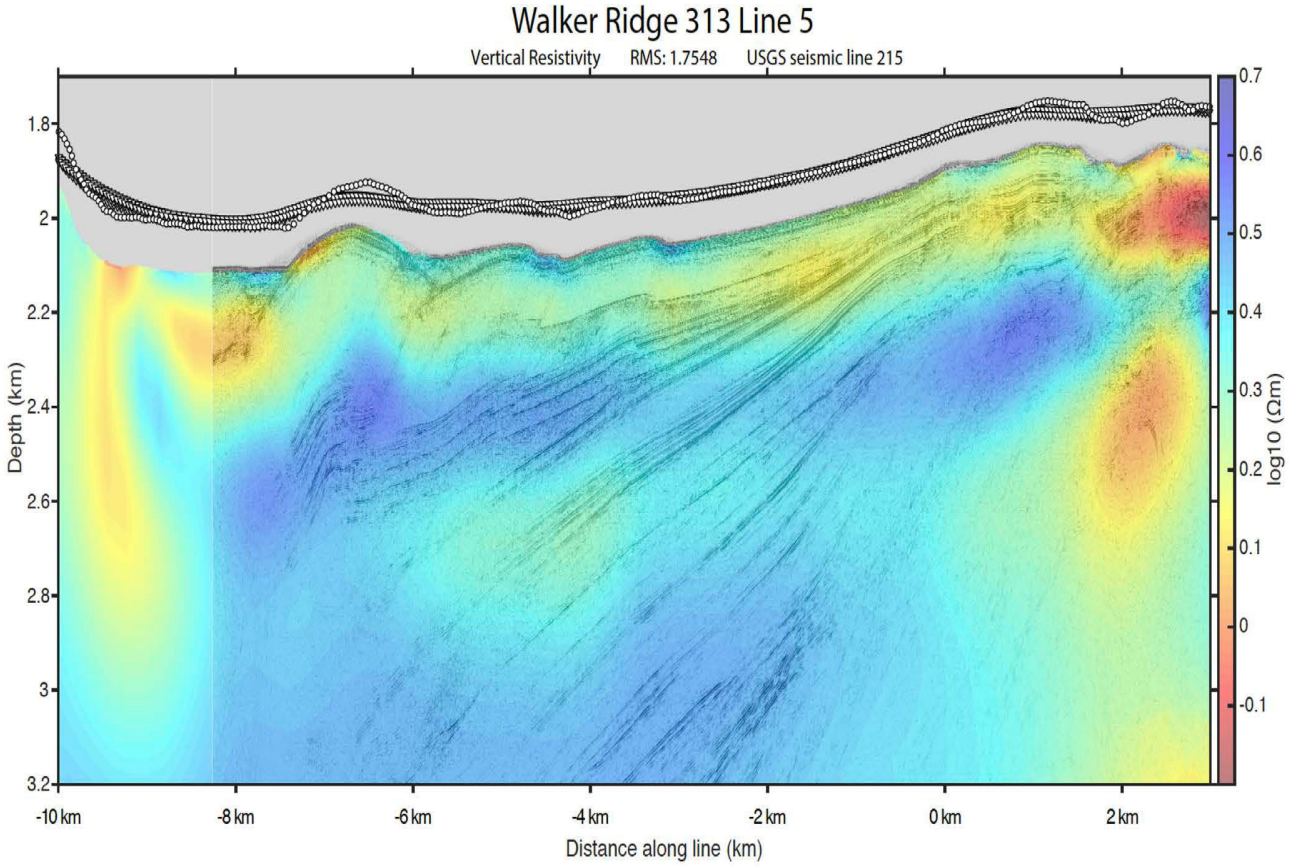

Figure 6: *CSEM data over Walker Ridge 313 gas hydrate occurrences discovered in 2009 and the target of the planned drilling in 2022 by UTA. The data show resistive intervals indicative of hydrocarbon (or, on either edge of the data, salt) in warm colors.*

In FY 2019, USGS completed an advanced processing flow on the MATRIX multichannel seismic data collected off the U.S. Atlantic Coast from the R/V *Hugh R. Sharp* in collaboration with DOE and BOEM during August 2018. USGS identified preliminary bottom simulating reflectors (BSR) in the dataset, which stretch from Hudson Canyon to Cape Hatteras. USGS presented this interpretation and the first estimates of inferred geothermal gradients at professional conferences. Twice in FY 2019, USGS transmitted versions of the processed data to BOEM and USGS also hosted a multi-day technical meeting with BOEM to review the data. USGS has begun preparing MATRIX data and associated metadata for an August 2020 formal public release and began work on advanced velocity analyses that combine MATRIX and USGS Law of the Sea seismic data to develop the most accurate conversion of travel time to actual depths. USGS also started formulating a machine learning framework to identify BSRs that are parallel to stratigraphy offshore New Jersey and the Commonwealth of Virginia using neural networks operating on advanced seismic attributes.

3. Numerical Simulation Studies

In addition to focused studies utilizing field data sets from India, Alaska, and the Gulf of Mexico, NETL has supported international collaboration and shared learning among scientists and engineers through two international gas hydrate code comparison studies. These code comparison efforts advance code capabilities and foster confidence in these critical analytical tools, through the exchange of information among gas-hydrate reservoir scientists and engineers engaged in the development, testing, and application of numerical simulators, as well as the comparison of simulation results against well-defined problems. The most recent international code comparison study, IGHCCS2, involved a community of participants from 21 institutions from around the world. The collaboration was designed to facilitate the ongoing integration of geomechanical phenomena into existing multiphase flow, thermal, and thermodynamic models. In FY 2019—under the guidance of NETL, USGS, the Pacific Northwest National Laboratory (PNNL), and the Lawrence Berkeley National Laboratory (LBNL)—the IGHCCS2 study completed the development of five benchmark problems, the solution submissions against those problems, and the comparison of the solutions. The study resulted in technical advances to nearly all numerical simulators of the participating teams, which established a legacy of solved problems for future numerical simulators and helped to resolve differences in simulation results.

In FY 2019, a major effort focused on continuing simulation efforts in support of proposed DOE-JOGMEC long-term hydrate reservoir response testing on the Alaska North Slope. Using an initial two-dimensional geological model derived from the well drilled in December 2018, NETL and JOGMEC modeling groups conducted collaborative modeling to better constrain the potential gas and water flow rates from the planned test. Also, in FY 2019, LBNL initiated focused simulation studies designed to inform well test design, including optimization of both completion interval and the pace of pressure drawdown.

A new non-empirical relative permeability model with capillarity was developed at NETL in FY 2019. Typically, numerical simulations of gas hydrate use fully empirical models that were originally developed for conventional oil and gas reservoirs. The new model with capillarity only

requires fitting the empirical parameters once with experimental data at any single gas hydrate saturation and then it can be used to predict relative permeability at any gas hydrate saturation.

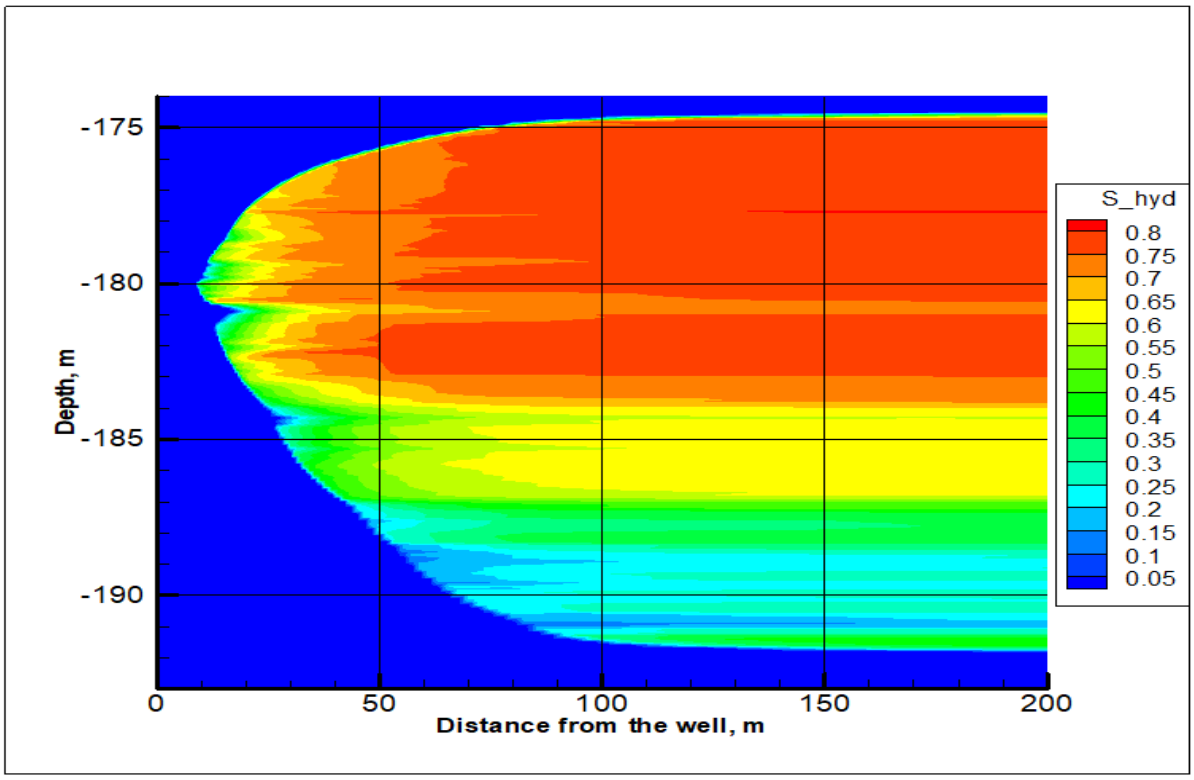

Figure 7: *Numerical simulation showing remainng gas hydrate saturation after one continuous year of depressurization; based on the primary "B-unit" target reservoir, Alaska North Slope.*

Also in FY 2019, the basin modeling team at Stanford University continued its investigation of the formation and dissociation of methane hydrates through geologic time at the basin scale. The focus of the effort is on the hydrate deposits located on the Hikurangi Ridge, which is on the offshore of New Zealand, and the hydrate deposits located in Walker Ridge 313, which were drilled by the JIP in 2009 and are currently slated for DOE-UTA pressure coring in FY 2022. The modeling effort examines the possible history of gas generation, migration, and hydrate formation through continuing sedimentation and various episodes of uplift, faulting, erosion, and sea-level change.

4. Experimental Studies

The pore habit of methane hydrate in sediment matrices (whether it coats grains, cements grains, "floats" in the pore space, or some combination) within actual hydrate accumulations remains undocumented. In FY 2019, NETL advanced toward that goal by successfully imaging (via micro computed tomography) methane hydrate at the pore scale synthesized in the lab into samples obtained in the Gulf of Mexico. The studies revealed that different conditions of hydrate formation will produce different hydrate pore habits. In addition, NETL was able to obtain the

initial images of native gas hydrate obtained and preserved within pressure cores obtained in the Gulf of Mexico in 2017 (Figure 8), which suggests a pore-filling structure.

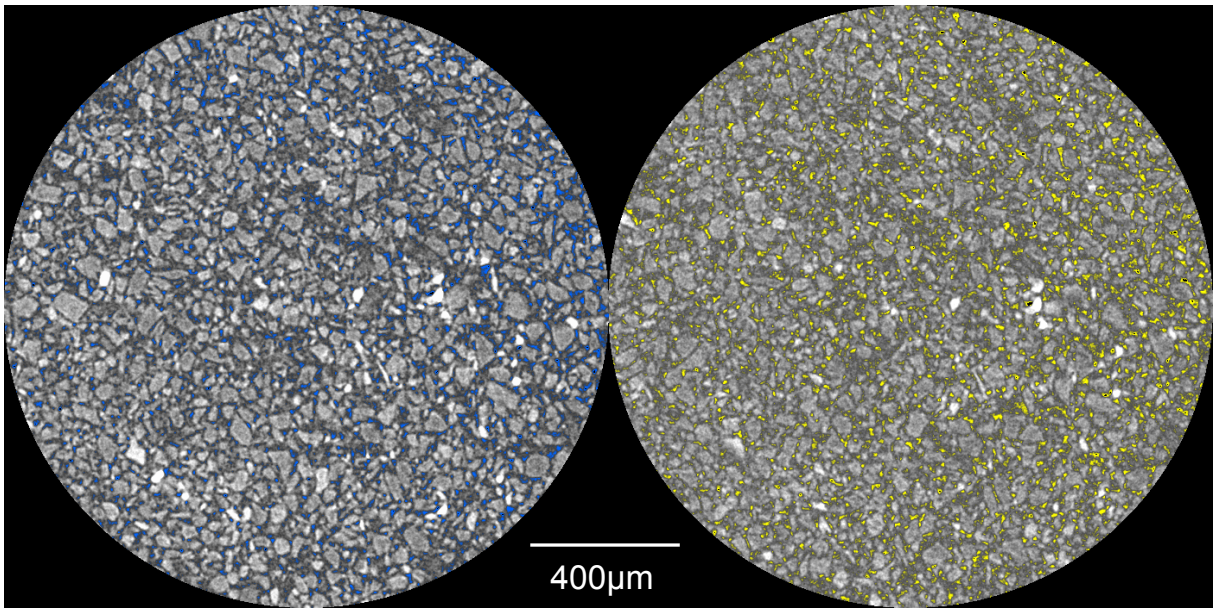

Figure 8. *Pore scale image of a sample extracted from a Gulf of Mexico pressure core and the same core after hydrate dissociation. Gas hydrate in the sample has been colored blue and the gas is yellow in color (NETL).*

In 2019, LBNL conducted a series of experiments at varying hydrate saturations and varying gas hydrate pore-filling modes as a means of providing laboratory data to allow comparison and calibration to the numerical simulation studies being conducted under the IGHCCS2 described above.

Louisiana State University and USGS completed a laboratory effort to assess the impact of changing pore fluid chemistry during hydrate dissociation on sediment migration and clogging. The study concludes that fine particles tend to collect at gas/water interfaces created by the multiphase flow of gas and water. Thus, as methane and fresh water flow from the hydrate-dissociation toward the production well, fine particles in the reservoir sands, interbedded fine-grained layers, and seal layers can be swelled, migrated, or both, potentially clogging pathways and limiting flow to the production well.

Texas A&M University, in partnership with LBNL and the Korea Institute of Geoscience and Mineral Resources (KIGAM), concluded a multi-year program of integrated laboratory study and numerical simulation focused on the investigation of the geomechanical response of depressurized gas hydrate systems. In 2019, researchers completed simulation-based and experimental studies of the evaluation of capillary pressure and relative permeability changes during simulated production.

5. International Collaboration

In FY 2019, DOE maintained active engagement with the leading international gas hydrate R&D programs. This engagement provides the Department access to critical data regarding the nature and evolution of geologic systems that produce gas hydrate, as well as insights on the performance of gas hydrate exploration and sampling technologies. Data sharing is facilitated through formal departmental-level agreements with the governments of Japan (Ministry of Economy, Trade, and Industry), India (Ministry of Petroleum and Natural Gas and Directorate General of Hydrocarbons), and South Korea (Ministry of Knowledge Economy). NETL maintains informal contacts with researchers in many other nations and will continue to monitor opportunities to expand international collaboration.

Direct collaboration with Japan's MH-21s research consortium is ongoing in Alaska (see above) and lessons learned in the offshore Japanese testing programs conducted by Japan in 2013 and 2017 continue to inform the program's collaborative plans for testing in Alaska. Extensive collaboration continues between USGS, Japan, and NETL with the National Gas Hydrate Program (NGHP) of India. In FY 2019, the final scientific reports on the collaborative analyses of samples and data acquired offshore India in FY 2015 appeared as part of a Special Issue of the *Journal of Marine and Petroleum Geology*. NETL, USGS, and Japanese scientists also continue to provide advice to NGHP's planning for future expeditions as well as research priorities for laboratory and modeling efforts being conducted at numerous NGHP-affiliated research institutions throughout India.

In FY 2019, research efforts at PNNL continued to emphasize collaborative numerical modeling efforts with KIGAM supported by the South Korean National Gas Hydrate Development Organization. The PNNL effort addressed the efficacy of gas hydrate production using nitrogen injection.

6. Support for Education and Training

NETL, through its cooperative agreements with academia, supports dozens of students obtaining advanced degrees across a wide range of scientific disciplines. In addition, in cooperation with the National Academies of Science (NAS), Engineering, and Medicine, NETL established the National Gas Hydrate R&D Program Fellowship in 2007. In FY 2019, Dr. Claire McKinley was selected as the newest NETL-NAS gas hydrate fellow (Figure 9). Dr. McKinley will conduct research at the University of Washington on "evaluating the extent of microbial Fe-reduction and its role in the global methane cycle" under Dr. Evan Solomon (a former NETL-NAS fellow).

Figure 9. *2019 NETL-NAS National Methane Hydrate Fellow, Dr. Claire McKinley.*

7. Program Management and Oversight

Throughout FY 2019, DOE managed multi-year R&D projects selected for funding in prior years. No new project starts were scheduled for FY 2019. DOE continued to engage its Methane Hydrate Advisory Committee in the evaluation of gas hydrate R&D priorities and progress by conducting thorough reviews of program activities at meetings in Houston, Texas on October 19-20, 2018 and in Galveston, Texas on April 23, 2019. Meeting presentations and minutes are available on DOE's website.

8. Technology Transfer

DOE and its research partners continued to disseminate research results to the scientific community during FY 2019. Appendices A1 and A2 of this report provide press releases related to the December 2018 drilling effort on the Alaska North Slope. Appendix B lists the 30 peer-reviewed publications and reports stemming from DOE support that were released during FY 2019. In addition, the DOE-NETL Gas Hydrate Newsletter, *Fire in the Ice*, continued to report on global developments in gas hydrate R&D. This periodical publication is distributed to approximately 1,500 subscribers in over 35 countries.

9. Conclusion

This report describes the activities and accomplishments of DOE's Gas Hydrate R&D program in FY 2019. DOE effectively managed international collaborations, work with National Laboratories, collaboration with other Federal and State agencies, and a portfolio of ongoing work with the private sector to further advance the science and technology needed to improve the understanding of the occurrence, nature, resource potential, and behavior of naturally-occurring gas hydrates. FY 2019 witnessed the continued delivery of scientific insight from the program. This insight was supported by extensive international and interagency collaboration and the continuous integration of work conducted in the lab in addition to the computer codes and data collected from field programs. Work also continued to improve key field sampling technologies that will be deployed in future drilling programs. DOE and its research partners continued to disseminate research results to the scientific community during FY 2019 through an extensive technology transfer program, including a widely-read newsletter.

The primary highlight of FY 2019 was the drilling of the Hydrate-01 Stratigraphic Test Well on the Alaska North Slope. The drilling program was achieved through extensive collaboration that was managed by NETL and conducted by its scientists and engineers, various organizations participating in Japan's MH-21s research consortium, USGS, PRA, Alaska DNR, and the Prudhoe Bay operators. Data obtained in that well confirmed that the site selected by the project is ideally suited to host long-term scientific tests of gas hydrate's response to controlled depressurization. That program is now working to refine scientific and operational plans for the test phase, and to resolve the complex legal and commercial agreements required to support needed testing to proceed.

Information on DOE's Gas Hydrate R&D program, including detailed summaries of all active and completed projects as well as reports and publications resulting from DOE-funded investigations, are regularly updated and can be found on NETL's website.

Further information on the program, including reports and activities of the Methane Hydrate Advisory Committee, are available on DOE's website.

Appendix A1: "The U.S. Department of Energy is part of an international team set to drill a gas hydrate test well on Alaska North Slope"

News Release: December 4, 2018

The U.S. Department of Energy's (DOE) National Energy Technology Laboratory (NETL), as part of an international partnership, will investigate the resource potential of natural gas hydrates within the Prudhoe Bay Unit (PBU) on the Alaska North Slope. NETL, in partnership with the Japan Oil, Gas and Metals National Corporation; the U.S. Geological Survey (USGS); and Petrotechnical Resources-Alaska have arranged with the Prudhoe Bay unit owners to drill and log an initial test well, as well as gather samples to confirm the occurrence of gas hydrate at a location in within the currently operating Prudhoe Bay oil field.

Gas hydrates are naturally occurring combinations of natural gas and water that form in specific conditions of relatively cold temperatures and relatively high pressures. Gas hydrates are known to occur in abundance on the Alaska North Slope, as well as in the shallow sediments of deepwater continental margins around the world—most notably in the Gulf of Mexico and off the southeastern coast of Japan.

"This test will move us closer to understanding gas hydrates, which have the potential to provide an enormous new energy source," said Steven E. Winberg, Assistant Secretary for Fossil Energy. "We look forward to working with our partners on this important project."

The initial well will feature temperature- and acoustic monitoring devices that will allow it to serve as a monitoring well for potential long-term field experiments. This effort builds upon prior gas hydrate field research conducted by both the United States and Japan, including successful short-duration tests in Canada in 2002, 2007, and 2008; Alaska in 2007 and 2012; and offshore Japan in 2013 and 2017. The work of the United States and Japan confirmed the occurrence of gas hydrates, identified many technical details of timing and nature, and demonstrated the technical feasibility of producing natural gas from the select hydrate deposits.

The next critical step is to conduct field experiments of sufficient duration to reveal how gas hydrates release natural gas in response to reservoir depressurization. The site in Alaska has the potential to provide a unique opportunity to conduct experiments over many months because the partnership with industry will allow access to sites on a year-round basis.

The collaborative effort has benefitted from the support of the Alaska Department of Natural Resources to facilitate gas hydrate evaluation in Alaska.

Appendix A2: "The U.S. Department of Energy, as part of an international team, has successfully drilled a gas hydrate test well on Alaska North Slope"

News Release: January 23, 2019

In a unique international effort, the U.S. Department of Energy (DOE) and the National Energy Technology Laboratory (NETL) have taken a significant leap forward in investigating the resource potential of natural gas hydrates within the Prudhoe Bay Unit (PBU) on the Alaska North Slope. DOE/NETL formed a partnership with the Japan Oil, Gas and Metals National Corporation, the U.S. Geological Survey (USGS), and Petrotechnical Resources-Alaska, in cooperation with the Prudhoe Bay unit owners, to successfully drill and log an initial test well (Stratigraphic Test Well). The well was located in the greater Prudhoe Bay Oil field, which has confirmed the occurrence of gas hydrates in two reservoirs that are suitable for future testing. The initial well was completed with temperature- and acoustic-monitoring devices in place that will allow it to serve as a monitoring well for any future field experiments.

"The success of this test moves us closer to characterizing, evaluating, and confirming the potential for gas hydrates production on the North Slope," said Steven E. Winberg, Assistant Secretary for Fossil Energy. "We look forward to continue working with our partners to conduct world-class gas hydrates research on the Alaska North Slope."

The location of this site in the greater Prudhoe Bay Oil field provides the necessary infrastructure to conduct field experiments of sufficient duration to reveal how gas hydrates release natural gas in response to reservoir depressurization.

In addition, this effort builds upon prior gas hydrate field research conducted by both the United States and Japan, including successful short-duration tests in Canada in 2002, 2007, and 2008; Alaska in 2007 and 2012; and offshore Japan in 2013 and 2017. The work of the United States and Japan has confirmed the occurrence of gas hydrates in both the United States and in Japan, identified many technical details of its occurrence and nature, and demonstrated the technical feasibility of producing natural gas from the reservoir.

The collaborative effort has benefitted from the support of the Alaska Department of Natural Resources to facilitate gas hydrate evaluation in Alaska.

Appendix B: CY 2019 Peer-Reviewed Publications and Reports

Collett, T., Kumar, P., Boswell, R., Waite, W., 2019. Preface: marine gas hydrate reservoir systems along the eastern continental margin of India: Results of the National Gas Hydrate Program Expedition 02. *Marine and Petroleum Geology* 108, 1-2.

Collett, T., Boswell, R., Waite, W., Kumar, P., Pratap, M., Roy, S., Kumar, S., Chopra, K., Singh, S., Yamada, Y., Tenma, N., Pohlman, J., Zyrianova, M., 2019. India National Gas Hydrate Program Expedition 02 summary of scientific results: Gas hydrate systems along the eastern continental margin of India. *Marine and Petroleum Geology* 108, 39-142.

Collett, T., 2019. Gas hydrate production testing – knowledge gained: *Proc. Offshore Technology Conference*, OTC-29516-MS, Houston, Texas, USA, May 6-9, 16 p.

Collett, T., 2019. USGS National and Global Oil and Gas Assessment Project-Northern Alaska Province, Gas Hydrate Assessment Unit Boundaries and Assessment Input Data Forms: U.S. Geological Survey data release, 12 p. https://doi.org/10.5066/P9HSWE98

Collett, T., Lewis, K., Zyrianova, M., Haines, S., Schenk, C., Mercier, T., Brownfield, M., Gaswirth, S., Marra, K., Leathers-Miller, H., Pitman, J., Tennyson, M., Woodall, C., Houseknecht, D., 2019. Assessment of undiscovered gas hydrate resources in the North Slope of Alaska, 2018: U.S. Geological Survey Fact Sheet 2019–3037, 4 p. https://doi.org/10.3133/fs20193037

Darnell, K., Flemings, P., DiCarlo, D., 2019. Nitrogen-Driven Chromatographic Separation During Gas Injection into Hydrate-Bearing Sediments, *Water Resources Research*, 55(8), 6673-6691. https://doi.org/10.1029/2018WR023414

Fang, Y., Flemings, P., Daigle, H., Phillips, S., Meazell, K., 2019. Petrophysical Properties of the GC 955 Hydrate Reservoir Inferred from Reconstituted Sediments: Implications for Hydrate Formation and Production, *AAPG Bulletin.* https://doi.org/10.1306/01062019165

Kim, J., Zhang, Y., Seol, Y. and Dai, S., 2019. Particle crushing in hydrate-bearing sands. *Geomechanics for Energy and the Environment*, p.100133.

Hancock, S., Boswell, R., Collett, T., 2019. Development of Deepwater Gas Hydrates. *Proc. Offshore Technology Conference*, OTC-29374-MS, Houston, TX.

Lei, L., Seol, Y., Choi, J-H., Kneafsey, T., 2019. Pore habit of methane hydrate and its evolution in sediment matrix – laboratory visualization with phase-contrasts micro-CT. J*. Marine and Petroleum Geology* 104, 451-467.

Lei, L., Liu, Z., Seol, Y., Boswell, R., Dai, S., 2019. An investigation of hydrate formation in unsaturated sediments using X-ray computed tomography. *J. Geophysical Research: Solid Earth* 124 (4), 3335-3349. https://doi.org/10.1029/2018JB016125

Lei, L., Seol, Y., Myshakin, E., 2019. Methane hydrate film thickening in porous media. *Geophysical Research Letters*, 46 (20), 11091-11099. https://doi.org/10.1029/2019GL084450

Lei, L., Seol, Y., 2019. High-saturation gas hydrate reservoirs - A pore scale investigation of their formation from free gas and dissociation in sediments. *J. Geophysical Research: Solid Earth,* 124 (12), 12430-12444. https://doi.org/10.1029/2019JB018243

Lu, R., Stern, L., Du Frane, W., Pinkston, J., Roberts, J., Constable, S., 2019. The effect of brine on the electrical properties of methane hydrate. *J. of Geophysical Research: Solid Earth*, 124, 10,877–10,892.

McConnell, D., 2019. Gas hydrate prospecting and characterization. *Proc. Offshore Technology Conference,* OTC-29604-MS. Houston, TX.

Moridis, G., Reagan, M., Queiruga, A., 2019. Gas hydrate production testing: design process and modeling results. *Proc. Offshore Technology Conference*, OTC-29432-MS. Houston, TX.

Moridis, G., Reagan, M., Queiruga, A., Kim, S., 2019. System Response to Gas Production from a Heterogeneous Hydrate Accumulation at the UBGH2-6 Site in the Ulleung Basin of the Korean East Sea. *J. Petroleum Science and Engineering*, 178, 655-665, https://doi.org/10.1016/j.petrol.2019.03.058

Moridis, G., Reagan, M., Queiruga, A., 2019. Simulation of Gas Production from Multilayered Hydrate-Bearing Media with Fully Coupled Flow, Thermal, Chemical and Geomechanical Processes Using TOUGH+Millstone, Part I: Numerical Modeling of Hydrates. *Transport in Porous Media,* 128 (2), 405-430, https://doi.org/10.1007/s11242-019-01254-6

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Phillips, S., Flemings, P., You, K., Meyer, D., and Dong, T., 2019. Investigation of in situ salinity and methane hydrate dissociation in coarse-grained sediments by slow, stepwise

depressurization, *Marine and Petroleum Geology*, 109, 128–144. https://doi.org/10.1016/j.marpetgeo.2019.06.015

Phillips, S., Flemings, P., Holland, M., Schultheiss, P, Waite, W, Jang, J., et al., 2019. High concentration methane hydrate in a silt reservoir from the deep-water Gulf of Mexico. *AAPG Bulletin*. https://doi.org/10.1306/01062018280

Portnov, A., Cook, A.., Heidari, M., Sawyer, D., Santra, M., Nikolinakou, M., 2019. Salt-driven evolution of a gas hydrate reservoir in Green Canyon, Gulf of Mexico, *AAPG Bulletin*. https://doi.org/10.1306/10151818125

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Santra, M., Flemings, P, Scott, E., Meazell, P., 2019. Evolution of Gas Hydrate Bearing Deepwater Channel-Levee System in Abyssal Gulf of Mexico – Levee Growth and Deformation. *AAPG Bulletin.* https://doi.org/10.1306/04251918177

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