U.S. DEPARTMENT OF ENERGY

Fiscal Year 2016 Methane Hydrate Program

Report to Congress
November 2017

United States Department of Energy
Washington, DC 20585

Message from the Secretary

The Department of Energy is required[1] to submit to Congress an annual report on the actions taken to carry out methane hydrate research.

I am pleased to submit the Report to Congress entitled, *Fiscal Year 2016 Methane Hydrate Program*. The report was prepared by the Department of Energy's Office of Fossil Energy, and summarizes the progress made in this area of research.

This report is being provided to the following Members of Congress:

- **The Honorable Michael R. Pence**
  President of the Senate
- **The Honorable Paul Ryan**
  Speaker of the House of Representatives
- **The Honorable Lisa Murkowski**
  Chairman, Senate Committee on Energy and Natural Resources
- **The Honorable Maria Cantwell**
  Ranking Member, Senate Committee on Energy and Natural Resources
- **The Honorable Lamar Smith**
  Chairman, House Committee on Science, Space and Technology
- **The Honorable Frank D. Lucas**
  Ranking Member, House Committee on Science, Space and Technology
- **The Honorable Greg Walden**
  Chairman, House Committee on Energy and Commerce
- **The Honorable Frank Pallone, Jr.**
  Ranking Member, House Committee on Energy and Commerce
- **The Honorable Thad Cochran**
  Chairman, Senate Committee on Appropriations
- **The Honorable Patrick Leahy**
  Vice Chairman, Senate Committee on Appropriations
- **The Honorable Rodney P. Frelinghuysen**
  Chairman, House Committee on Appropriations

[1] 30 U.S.C. 2003(e)(5).

- **The Honorable Nita M. Lowey**
  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**
  Vice Chairman, Senate Subcommittee on Energy and Water Development
  Committee on Appropriations
- **The Honorable Mike Simpson**
  Chairman, House Subcommittee on Energy and Water Development
  Committee on Appropriations
- **The Honorable Marcy Kaptur**
  Ranking Member, House Subcommittee on Energy and Water Development
  Committee on Appropriations

If you need additional information, please contact me or Ms. Jennifer Loraine, Deputy Assistant Secretary for Senate Affairs, Mr. Marty Dannenfelser, Deputy Assistant Secretary for House Affairs, at (202) 586-5450, or Mr. Joseph Levin, Associate Director of External Coordination in the Office of the Chief Financial Officer, at (202) 586-3098.

Sincerely,

Rick Perry

Rick Perry

Rise Peace

Executive Summary

This report describes actions taken in Fiscal Year (FY) 2016 to implement the Department of Energy's (DOE) methane hydrate research and development program (the Program)[2]. This report outlines key activities and accomplishments of the program during FY 2016 and provides a bibliography of 30 peer-reviewed papers that appeared during the year. The Energy Policy Act of 2005 stipulated that the Secretary of Energy provide this report to Congress annually.

The Program is managed within the Department of Energy by the Office of Fossil Energy, Office of Oil and Natural Gas, and conducted through the National Energy Technology Laboratory (NETL). The fundamental goals and nature of the Program remained as in prior years – conduct collaborative R&D to deliver science and technology to further understand the nature and regional context of gas hydrate deposits, the physical properties and characteristics of gas hydrate-bearing sediments, and the environmental implications of naturally-occurring methane hydrate.

In FY 2016, the Program received $19.8 million in direct appropriations for R&D related to methane hydrates. With this funding, the Program continued its cooperative efforts with the private sector, DOE National Laboratories, and international partners to advance the science and technology associated with naturally-occurring methane hydrate. The Program's major efforts continued to focus on the following: 1) preparations for further deepwater characterization and sampling in the Gulf of Mexico; 2) consideration of potential long-term reservoir response experiment opportunities on the Alaska North Slope in partnership with Japan, industry, the U.S. Geological Survey, and the Alaska Department of Natural Resources; 3) field programs to assess gas hydrate's role in changing natural environments; and 4) opportunities to collaborate with ongoing international programs, most notably with India, Japan, and South Korea.

[2] Authorized by the Methane Hydrate Research and Development Act of 2000 (30 U.S.C. 2001, *et seq*; Public Law 106-193), as amended by section 968 of the Energy Policy Act of 2005 (Public Law 109-58) (EPAct).

FISCAL YEAR 2016 METHANE HYDRATE PROGRAM

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I. Legislative Language

This report describes actions taken in Fiscal Year (FY) 2016 to implement the Methane Hydrate Research and Development Act of 2000, as amended by Section 968 of the Energy Policy Act of 2005 (EPAct). EPAct requires the Secretary of Energy provide this report to Congress annually.

II. Summary of Accomplishments in FY 2016

In FY 2016, the Methane Hydrate Program continued advancement of gas hydrate science and technology through various national laboratory projects, interagency agreements, and cooperative agreements with the private sector (primarily with universities). There were several key events and activities: (1) preliminary evaluation of costs and risks of conducting field operations on both unleased lands and developed Prudhoe Bay Unit lands on the Alaska North Slope; (2) the determination to consider gas hydrate testing opportunities within the greater Prudhoe Bay infrastructure area in collaboration with Japan, the U.S. Geological Survey (USGS), and the State of Alaska; (3) advancement in planning and equipment readiness for field programs to evaluate known gas hydrate occurrences in the deepwater Gulf of Mexico (GOM); (4) continued collaboration with USGS and India in evaluation of gas hydrate occurrences and preparations for gas hydrate field testing opportunities in the Indian Ocean; and (5) further field evaluations of gas hydrate occurrence and methane dynamics in climate sensitive portions of the U.S. Outer Continental Shelf (OCS).

The following summarizes key activities in FY 2016 in eight topical categories.

1. *Gas Hydrate Characterization Technologies*

A key goal of the program in FY 2016 was to continue its efforts to refine knowledge of the scale and nature of occurrence of gas hydrate on the U.S. OCS. From 2001 to 2014, the flagship project in this effort had been the GOM Gas Hydrates Joint Industry Project (JIP). This JIP was a cooperative research program between the DOE (in coordination with the USGS, the U.S. consortium of industry and academic partners under the leadership of Chevron. A primary goal of the JIP was to test the ability to find and characterize gas hydrate through integrated geology and geophysics analyses, by selecting several prospective sites and testing those selections through deepwater drilling and logging programs.

The JIP's 2009 "Leg II" drilling program was fully successful in this regard, and global gas hydrate exploration and evaluation now rely heavily on its concepts of direct detection of gas hydrate through tailored application of established oil and gas prospecting approaches. In 2015, this approach was again proven successful by the discovery of thick gas-hydrate bearing sands in the Bay of Bengal, offshore as part of a program conducted by the government of India utilizing

experts from DOE's National Energy Technology Laboratory (NETL), the USGS, and the Department of the Interior Bureau of Ocean Energy Management (BOEM) to assist in the site selection process.

In order to maximize the number of sites that could be evaluated, the JIP's 2009 expedition relied solely on collection of logging data, and did not acquire cores (a time-consuming and more expensive process). A third expedition with the JIP was then planned with the goal of acquiring core samples under pressure to answer critical questions related to the chemistry and source of the gas, and the geomechanical and petrographic (for example, permeability) nature of the hydrate-bearing sediments.

From 2012 to 2014, the JIP worked in collaboration with Japan Oil, Gas and Metals National Corporation (JOGMEC) and the National Institute of Advanced Science and Technology (AIST), the USGS, and Georgia Tech to further the development and testing of deepwater pressure-coring tools and compatible pressure-core analysis devices. The tools were transferred to DOE in early 2014 as uncertainty related to new GOM regulations were emerging which prompted the JIP to end its effort in gas hydrates. In general, in the aftermath of the Deepwater Horizon incident and the subsequent creation of the Bureau of Safety and Environmental Enforcement and Bureau of Ocean Energy Management, and the attendant uncertainty regarding potential new rules that might be implemented on a range of issues from blow-out preventers to relief well preparedness made it difficult to plan or cost any future JIP drilling program.

In the first quarter of FY 2015, NETL conducted an open solicitation that resulted in a new award to the University of Texas-Austin (UT-A). This project is designed to conduct field operations to assess the nature and origin of gas hydrates in the Gulf of Mexico. In FY 2015, the project conducted successful lab/bench testing of a modified version of DOE's Pressure Coring Tool and developed scientific plans for two expeditions. The first expedition to gather cores at one site from the 2009 JIP expedition; and a second expedition to visit a range of sites to better understand the dynamics and physical controls on the nature of gas hydrate occurrence in the GOM.

In FY 2016, the UT-A project completed science planning, ship scheduling, and permitting activities required to conduct an initial expedition in May 2017, which was completed as scheduled. This expedition was a focused, two-well, pressure-coring program at the Green Canyon (GC) 955 site conducted from the Helix Vessel Q4000. In planning this expedition UT-A and NETL successfully addressed and resolved an array of legal liability issues associated with marine field expeditions.

In addition, during FY 2016 the project continued to advance planning for a multi-site, drilling, logging, and coring program (**Figure 1**) designed to occur within the framework of the International Ocean Discovery Program (IODP). This second expedition would leverage funding from the IODP for both liabilities and primary costs and drilling/coring from their dedicated research drillship, the *Joides Resolution*. The UT-A proposal was reviewed by separate Scientific Merit and Safety panels of the IODP in FY 2016 with further review (and anticipated final

expedition approval and scheduling) to occur in FY 2017. The two expeditions will result in a comprehensive and integrated science program that will evaluate the nature, occurrence, and dynamics of gas hydrate reservoir systems in different geologic settings in the Gulf of Mexico.

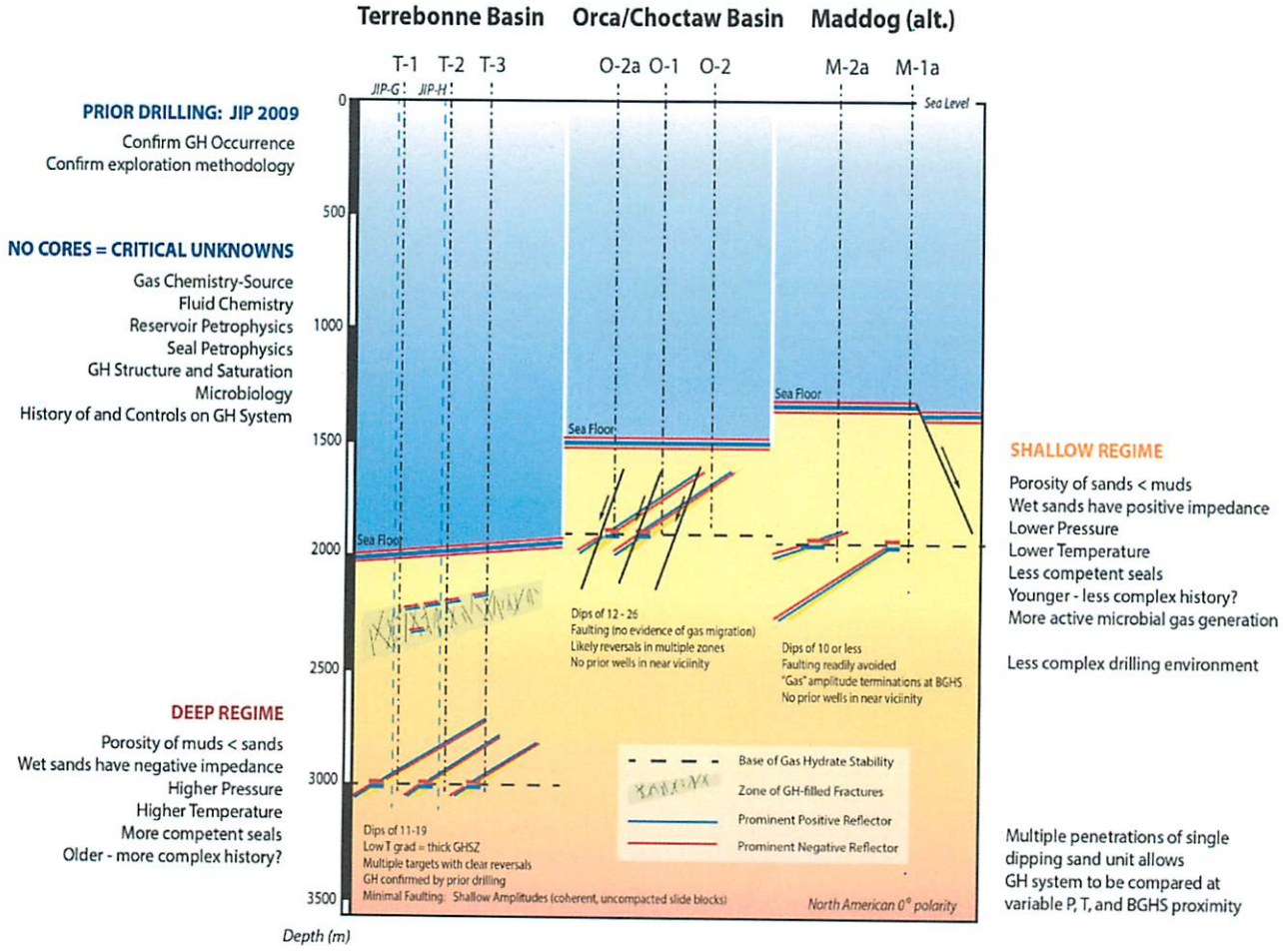


Figure 1: *Schematic depiction of the sites and science objectives for a multi-basin drilling and coring expedition as proposed to the International Ocean Discovery Program.*

Several other ongoing projects focusing on characterization of gas hydrates in the GOM continued toward conclusion during FY 2016. Interpretation and evaluation continued following a 2013 co-funded USGS, BOEM, and DOE expedition that collected high-resolution 2-D and 3-D seismic data over the locations of the JIP Leg II drilling (final reports were published in early FY 2017). Oklahoma State concluded its effort to utilize JIP Leg II log data to validate and advance rock-physics models required to infer gas hydrate occurrence and saturation utilizing standard industry seismic data. Ohio State University completed its review of ~2,700 industry wells drilled through the gas hydrate stability zone and reported that 788 of the wells gathered data sufficient to evaluate the occurrence of gas hydrate and that gas hydrate was present in at least 116 wells.

Finally, a new FY 2016 solicitation resulted in the award of a new cost-shared project in the area of gas hydrate characterization via remote sensing to the University of California at San Diego

Scripps Institution of Oceanography. This project will further assess the viability of controlled source electromagnetic (CSEM) technologies for locating marine hydrate deposits by collecting new CSEM at well-characterized GOM sites. CSEM, which is based on formation resistivity, could provide a useful compliment to seismic approaches which are based on sediment mechanical strength.

2. Gas Hydrate Production Technologies

The Program's efforts to determine the technological basis for gas recovery from natural gas hydrates is focused on field experiments conducted in partnership with the USGS, industry, international partners, and the State of Alaska; and is supported by focused experimental and numerical simulation work at the DOE's Lawrence Berkeley, Pacific Northwest, Lawrence Livermore, and National Energy Technology National Laboratories (DOE National Laboratories).

Field programs in Alaska began in FY 2004 with a test well in partnership with Maurer-Anadarko that failed to encounter gas hydrate. The lessons of that well were used to drive a more comprehensive, petroleum systems-based, and interagency approach within a project conducted with BP Alaska, Inc. that drilled and sampled thick gas hydrate accumulations at the "Mt. Elbert" test well in the Milne Point Unit FY 2007. That well, which was required to be drilled from a temporary ice pad, as opposed to permanent gravel infrastructure, proved the Program's exploration approach and the ability to conduct research safely and non-disruptively within an area of ongoing industry oil and gas operations. As a result, from 2008-2010, DOE was able to discuss gas hydrate field programs with the broader industry partnership that holds the leases over the most prospective field sites within the Prudhoe Bay Unit (PBU). Plans for a long-term reservoir response experiment (including separate boreholes for experiments related to CO_2 injection/chemical exchange and depressurization) from a gravel pad within the PBU were generated in 2010. However, due to site access issues plans were later modified to a short-duration test focused on chemical exchange in partnership with ConocoPhillips and Japan.

In early FY 2014, both BP Alaska and ConocoPhillips indicated that they were no longer interested in entertaining cooperative research and development (R&D) with the government on gas hydrate in Alaska. To address this downturn in interest with respect to a long-term reservoir response experiment, the Alaska Department of Natural Resources (DNR) and DOE's Office of Fossil Energy signed a Memorandum of Understanding (MOU) in FY 2014 designed to facilitate gas hydrate field programs on the Alaska North Slope. The Alaska DNR set aside 11 large tracts of unleased lands adjacent to the Milne Point and Prudhoe Bay units until such time as DOE could determine if a feasible gas hydrate field experiment could be conducted.

In FY 2015, NETL collaborated with JOGMEC and the USGS to review the available data to assess the presence and nature of gas hydrates within the set-aside acreage. That review concluded that the state land sites were not conducive for long-term testing due to high costs and high risks associated with lack of infrastructure and uncertain occurrence of gas hydrate deposits. Also in FY 2015, the MOU between the Alaska DNR and DOE created new interest from the PBU partners (BP Exploration Alaska, ExxonMobil, ConocoPhillips, and Chevron) to consider gas hydrate proposals.

In FY 2016, prompted by the renewed receptiveness among the PBU partners to consider proposals for field work that could be conducted with minimal impact on ongoing unit operations, NETL, JOGMEC, USGS, and the Alaska DNR collaborated with the PBU partners to assess specific drill sites within the PBU. A specific location at the site of an unused exploration pad was identified, and a draft plan for operations was developed. This plan calls for a three-well program consisting of an initial stratigraphic test well to confirm and select the primary test reservoir, followed by a well dedicated to core acquisition and conversion to a monitoring well, and finally by the actual reservoir response test well (**Figure 2**). Critical issues governing whether the PBU partners will enable the test include determination of who will operate the well, how the liabilities associated with the field program will be handled, and how the impact of the test (such as assignment of a drill rig and disposal of produced gas and fluids) will be managed and minimized.

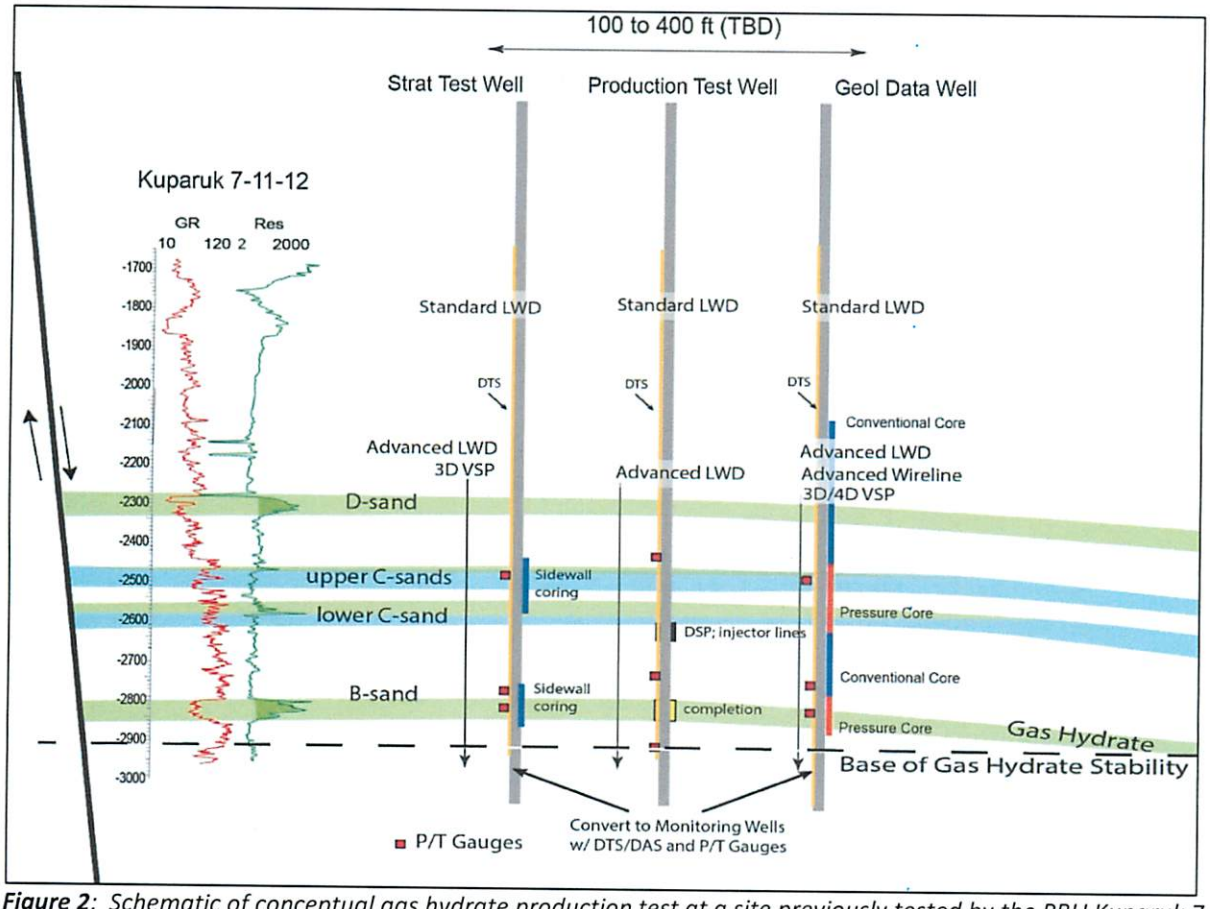


***Figure 2**: Schematic of conceptual gas hydrate production test at a site previously tested by the PBU Kuparuk 7-11-12 site in the westend Prudhoe Bay Unit, Alaska North Slope. The "stratigraphic test" well would be drilled first, and assuming success, the project would then drill and instrument "geologic data/monitoring" and "production test" wells. The test is conceived to extend for a year or more. Actual conduct of the test is contingent on availability of budgets and viable agreements between DOE, its partners in Japan, and the PBU Partners.*

A second initiative related to gas hydrate production evaluation is the engagement and support by NETL, Lawrence Berkeley National Laboratory (LBNL), and the USGS for the planning of potential production test wells offshore India. In FY 2016, NETL delivered an initial review of

simulations of production response for reservoirs discovered during India's 2015 drilling program. A key aspect of this effort is the full integration of geomechanical phenomena (grain movement, reservoir displacement, and seal integrity) and thermal conductivity into reservoir models for specific potential production test sites. This effort is being aided by ongoing collaboration with research institutes in Japan, at which advanced evaluation of the samples acquired offshore India in 2015 were conducted.

3. Gas Hydrate Environmental and Global Climate Studies

In FY 2016, DOE continued to support a range of studies designed to determine the sources, sinks, and fluxes of methane in gas-hydrate-bearing environments that may be most sensitive to ongoing environmental change. The primary goal is to understand the role gas hydrate might play in natural geohazards, in the global cycling of carbon over long time frames, and in the potential nearer-term feedbacks in response to warming climates. This effort reflects the intent of the original Methane Hydrate Research and Development Act, which directs DOE to work with our interagency partners to enable research across a broad range of gas hydrate issues, including the impacts of natural degassing from hydrates.

On the Pacific Margin, the University of Washington continued to gather and evaluate data on methane sources, sinks, and fluxes offshore Washington. The latest modeling efforts document the sensitivity of gas hydrate stability to current observed and future changes in bottom-water temperature. Ongoing work is addressing the source of the methane and any potential linkages to gas hydrate.

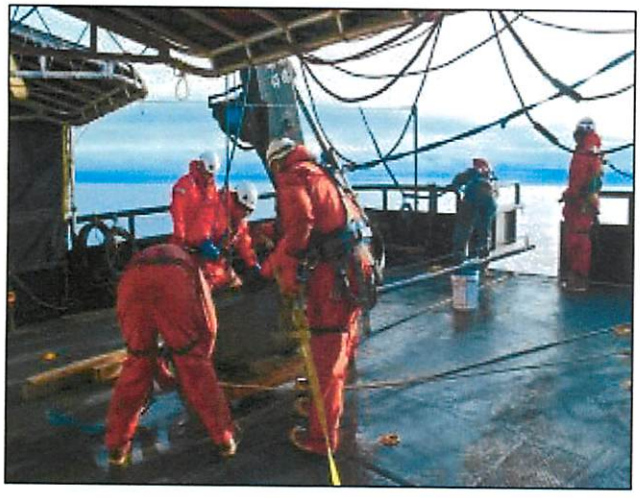


Figure 3: *Crew of the M/V Horseman and scientists from SMU and Oregon State securing heat flow probe, Beaufort Sea, offshore N. Alaska; September 2016.*

In late FY 2016, Southern Methodist University and collaborators conducted a research cruise to collect heat flow and chirp seismic reflection data in the Beaufort Sea (**Figure 3**). From the research vessel M/V Norseman II, the team collected 1,400 temperature data points from 113 probe deployments on four separate transects running from the upper edge of the margin, in water depths as shallow as ~200 meters to a maximum depth of ~1700 meters. Approximately ~200 kilometers of 12 kilohertz chirp echosounder data were collected.

Also in the Beaufort Sea, the University of California San Diego (UCSD) - Scripps Institute of Oceanography completed its effort to map sub-sea "relict" permafrost using newly designed CSEM imaging. The project results showed success in mapping permafrost and significant variability in permafrost preservation offshore following post-ice age inundation. It also showed

preferential preservation of permafrost and gas hydrate stability in areas associated with freshwater influx from major rivers. A related regional effort with USGS has determined permafrost extent through use of seismic reflection data and has concluded that relict permafrost is largely restricted to shallow waters (25 meters or less) within 40 kilometers of the present shoreline.

The Department of Energy supported research with the USGS that has also revealed the previously unknown extent of methane venting along the Atlantic Margin from geophysical data. USGS participated in one deep submersible dive in June 2016 as part of an ongoing effort to verify seep occurrence and methane release rates. In FY 2016, a new collaboration between the University of Rochester and the USGS was awarded that will advance understanding of the environmental implications that methane leaking from dissociating gas hydrates along the Atlantic Margin could have on the ocean-atmosphere system.

The Norwegian island of Svalbard is perhaps the best-characterized setting where gas hydrate dissociation is thought to be occurring as the landward edge of deepwater gas hydrate stability retreats downslope in response to warming bottom water. Major funding for a series of expeditions to the area to verify methane seepage and linkages to gas hydrate were staged by University of Tromsø (Norway) and University of Bremen (Germany) **(Figure 4)**. DOE-funded activities in FY 2016 included participation of scientists from Oregon State and the University of New Hampshire (UNH) in 5 cruises; supported deployment of Integrated Carbon Observation System (ICOS) instrumentation for methane measurement; and funded ongoing shore-based chemical and microbiological analyses. Preliminary results from the DOE-funded activities are expected to be published in FY 2017.

Figure 4: *DOE supported the participation of US scientists in a series of marine expeditions conducted by the Centre for Arctic Gas Hydrate, Environment, and Climate (CAGE; U. Tromsø) and at MARUM (U. Bremen) that are testing past interpretation that ongoing ocean warming is accelerating gas hydrate dissociation and methane release in the northern Atlantic.*

A new project awarded in FY 2016 will allow Texas A&M University to leverage prior data collected in the GOM with experimental results obtained at NETL to study the fate of methane in water columns where hydrate shells form around methane bubbles in a process called hydrate bubble armoring. The project will provide key insight into the potential for methane released at

the seafloor to reach the atmosphere. Substantial coordination with USGS and UNH researchers is occurring.

4. Fundamental Experimental and Modeling Studies

In FY 2016, the Program continued its support of focused experimental and numerical modeling studies to provide foundational science regarding the nature of hydrate-bearing sediments and their potential response to changes in their environment, either natural or induced.

During FY 2016, NETL's Research and Innovation Center (R&IC) continued to conduct numerical simulations, experimental studies, and analytical tool development to support the programs' international collaborations and major field projects in Alaska and the GOM. The work has focused on the generation of appropriate models, input data, and approaches for the challenging issues of full 3-D modeling of thinly-interbedded sand and mud sequences. R&IC and LBNL conducted initial simulations of the potential response of hydrate reservoirs offshore India to support Indian production test planning design.

LBNL and Pacific Northwest National Laboratory (PNNL) continued collaboration with the Korea Institute of Geoscience and Mineral Resources (KIGAM) in both numerical simulation and experimental studies related to gas production from marine gas hydrates. R&IC completed the design of a new state-of-art pressure core manipulation and characterization tool that will be employed to provide pore-scale imaging and evaluation of samples acquired in the FY 2017 and subsequent field programs. USGS participated in evaluation of pressure cores collected in India and evaluated in Japanese laboratories. An agreement to receive cores under pressure for transfer to the USGS Laboratory in Woods Hole, MA for analysis was completed.

Four projects selected and funded in prior fiscal years continued through FY 2016. Georgia Tech continued its experimental effort to address fundamental issues associated with the hydraulic and geomechanical behavior of gas hydrate in clay-rich sediments. The work is designed to assess any potential for viable commercial recovery from such deposits. A second project with Georgia Tech conducted successful field tests of a borehole-deployed tool for collection of geomechanical properties of hydrate-bearing sediments, which may provide means for collecting in-situ data on properties that can now only be obtained through collection, extraction, and evaluation of pressure cores. The Colorado School of Mines continued its effort to assess the relationship between gas hydrate content and various acoustic properties of hydrate-bearing sediment. The University of Texas-Austin continued its theoretical modeling efforts designed to assess the potential methane migration and accumulation mechanisms at a high-saturation, sand-hosted hydrate deposit in the GOM.

Three new projects were added to the portfolio in FY 2016. A project with the University of Texas at Austin that will conduct laboratory evaluation of the dynamic petrophysical attributes of gas hydrate–bearing sands in response to pressure reduction at macro- and micro-scale. This research will enhance the understanding of hydrate system behavior and improve the ability to simulate flow from gas hydrate reservoirs. A second new project with Louisiana State University will conduct a laboratory evaluation of the nature and implications of fine-grain sediments

migration during potential gas production, with specific focus on factors unique to hydrate-bearing sediments such as profound reductions in formation water salinity. A third new project features a collaboration between Texas A&M University and KIGAM that will leverage prior state-of-the-art experimentation using KIGAM's range of large-scale hydrate reactors to advance the integration of geomechanical capabilities into leading numerical model for hydrate system thermodynamic and hydraulic behavior.

5. International Collaboration

The Department of Energy maintained active engagement and discussion with the world's leading international gas hydrate Research and Development (R&D) programs in FY 2016. Formal departmental-level agreements continued with the governments of Japan (Ministry of Economy, Trade, and Industry) and Korea (Ministry of Knowledge Economy). A recently expired prior agreement with India (Ministry of Petroleum and Natural Gas) was also reinstated in FY 2016.

The primary focus of collaboration with Japan continues to be the pursuit of field testing programs on the Alaska North Slope. Interaction during FY 2016 was extensive, including meetings held in Denver (November 2015) and Anchorage (June 2016) and regular (bi-weekly) web-ex conference in the joint pursuit of a long-term reservoir response experiment on the Alaska North Slope.

Collaboration with India is focused on joint evaluation of drilling sites and operational plans for a proposed third Indian National Gas Hydrate Program (NGHP) to be conducted in FY 2017 (or perhaps FY 2018) at one or more sites discovered in the FY 2015 Indian offshore expedition in the Bay of Bengal. NETL, USGS, and LBNL continue to support planning primarily through the development of geologic models for the prospective sites and a series of integrated numerical simulation studies intended to support detailed field test design. The ongoing modeling effort is supported by collaboration between USGS and AIST (Japan) scientists in the advanced evaluation of pressure cores collected during the Indian government's FY 2015 expedition.

Research efforts at PNNL and LBNL in FY 2016 included continued collaborative numerical modeling efforts with KIGAM as enabled by the Korean National Gas Hydrate Development Organization (GHDO). Collaboration with South Korea was also expanded via the new project award to Texas A&M University, which includes extensive collaboration and cost share with KIGAM scientists.

NETL maintains informal contacts with researchers in many other nations (Mexico, Brazil, New Zealand, China, and others) and will continue to monitor opportunities to expand international collaboration.

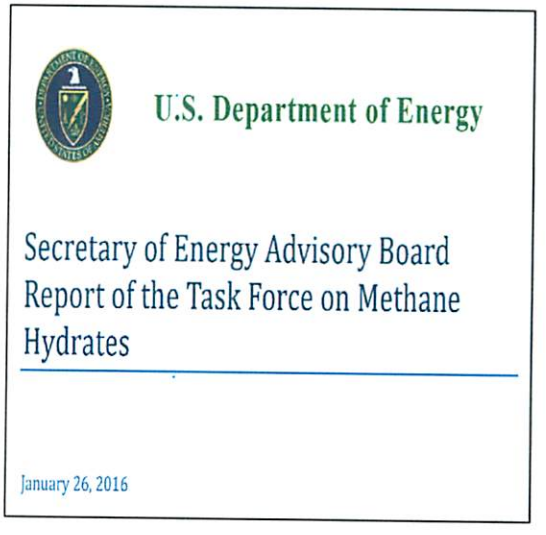
6. Support for Education and Training

Figure 5: *FY 2016 NETL-NAS National Gas Hydrate R&D Program Fellow Dr. Benjamin Phrampus.*

NETL, through its Cooperative Agreements with academia, is currently supporting dozens of students obtaining advanced degrees across a wide range of scientific disciplines. In addition, in cooperation with the National Academies, NETL established the National Gas Hydrate R&D Program Fellowship in 2007. In FY 2016, the latest research Fellowship was awarded to Dr. Benjamin Phrampus of Oregon State University (**Figure 5**). Dr. Phrampus's research is mentored by Dr. Robert Harris and Dr. Anne Trehu and is focused on evaluating the stability of marine gas hydrates at mid- to low-latitudes in response to environmental changes such as bottom-water warming.

7. Program Management and Oversight

Throughout FY 2016, DOE continued to manage a broad portfolio of R&D projects and conducted a new project solicitation that resulted in the announcement of the selection of six new projects that are to receive a total of $3.8 million in funding through FY 2018 (See Appendix A). In FY 2016, $2.0 million was provided for the six projects. Those projects are reviewed above under the specific R&D topics to which they most directly relate.



In response to a request from the Secretary, in FY 2016, a special Task Force of the Secretary of Energy Advisory Board (SEAB) reported on its findings related to the progress, direction, and justification for federally-funded R&D for gas hydrates. The panel's primary conclusions are as follows:

- *The program has made valuable scientific contributions since 2000 and should remain a DOE priority. Funding should remain at its current Fiscal Year (FY) 2015 level of $15 million per year. Given the long-term nature of the program, there should be greater funding certainty than in the past. Approximately one-third of the program budget should be dedicated to fundamental scientific questions whose answers are necessary for understanding methane hydrates as an energy resource and their environmental impact. Two-thirds of the program budget—approximately $10 million per year—would be used to support U.S. participation in larger international hydrates activities and complex field research (Executive Summary).*

- *The task force recognizes that the methane hydrate research program is answering fundamental, long-term questions about the technical and economic viability of producing methane hydrates—questions not likely to be addressed by industry due to lack of foreseeable commercial operations (page 2).*

- *Understanding methane hydrates cannot happen in a laboratory. Addressing many of the fundamental questions underlying hydrates exploitation and its environmental impact will require direct field observations and drilling (page 5).*

- *The potential contribution of fossil carbon to the atmosphere through the commercial extraction of methane from hydrate reservoirs is relatively small compared to that of other fossil resources (page 7).*

- *International funding now far exceeds U.S. federal funding; however, the United States still maintains the world's scientific and technological leadership on fundamental hydrate research. The contribution of U.S. expertise enhances the ability of collaborative efforts to improve international energy security (page 7).*

Also in FY 2016, the Program continued to manage a range of ongoing projects, field work proposals, and interagency agreements. Program oversight activities in FY 2016 included continued engagement via the NETL-led Interagency Technical Coordination Team (TCT). A meeting of the TCT (DOE/NETL, USGS, BOEM, BLM, NOAA, NSF, and NRL) took place on January 28, 2016. The Program's Federal Advisory Committee did not meet during FY 2016.

8. Technology Transfer

DOE and its research partners continued to disseminate research results to the scientific community during FY 2016. Appendix B lists 31 peer-reviewed publications that were released during FY 2016 which were the result of, in whole or in substantial part, DOE support. In addition, the DOE/NETL Gas Hydrate Newsletter, *Fire in the Ice*, continued to report on global developments in gas hydrate R&D. This periodic publication is distributed to approximately 1,500 subscribers in more than 35 countries.

FY 2016 highlights included early reports on landmark findings of the 2015 Indian NGHP-02 expedition, as well as updates on R&D activities in the Black Sea and in the northern Atlantic. In addition, early in FY 2016, as part of the 2015 Quadrennial Technology Review, DOE published a Gas Hydrates Technology Assessment[3]; an exhaustive review of the state of the art of gas hydrate research and development technology (**Figure 6**). FY 2016 peer-reviewed publications are highlighted by an NETL-facilitated international review on the state-of-the-art in gas hydrate exploration as a special section in the AAPG/SEG Publication, *Interpretation*. NETL also facilitated

[3] The Gas Hydrates Technology Assessment can be viewed at: https://energy.gov/sites/prod/files/2016/03/f30/QTR2015-7C-Gas-Hydrates-Research-and-Development.pdf

the release of the first peer-reviewed summary of the findings and implication of the 2011/2012 *Iġnik Sikumi* field program in the American Chemical Society Journal *Energy & Fuels*.

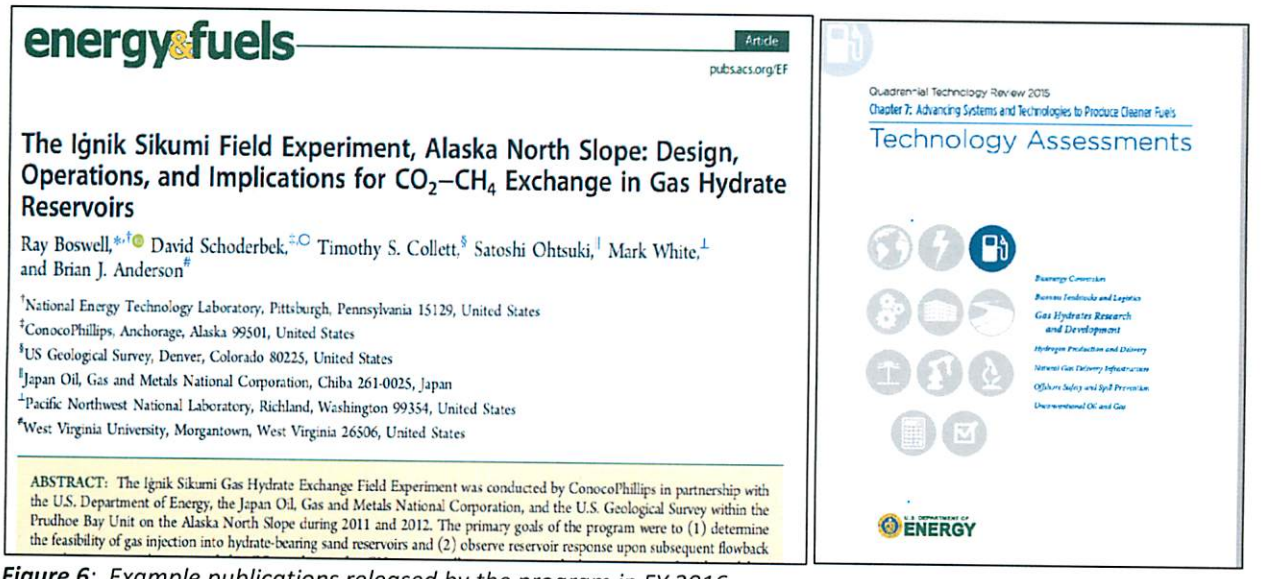


***Figure 6**: Example publications released by the program in FY 2016.*

NETL's Dr. Ray Boswell, along with colleagues from the USGS and India's ONGC conducted a topical luncheon panel at the 2016 Offshore Technology Conference meeting in Houston. The luncheon attracted an overflow crowd for a review of the current status of gas hydrate resource evaluation with particular focus on the findings from the 2015 expedition offshore India.

III. Conclusion

This report describes the activities and accomplishments of the DOE's Methane Hydrate R&D Program during FY 2016. DOE effectively managed its international collaborations, its work with DOE's National Laboratories, its collaboration with other Federal agencies, and its portfolio of ongoing work with the private sector to further advance science and technology development activities designed to determine the occurrence, nature, resource potential, and environmental implications of gas hydrate.

The Program's international activities were highlighted by ongoing and extensive collaborations with Japan, India, and South Korea. Collaborative work with Japan included an ongoing effort to develop long-term gas hydrate reservoir response field testing program on the Alaska North Slope, an effort that NETL continues to coordinate with the State of Alaska and the USGS. Collaboration with India in FY 2016 featured the development of geologic and engineering models to support a proposed major deepwater production test as envisioned by the government of India.

DOE's effort to characterize U.S. offshore gas hydrate resources was highlighted in FY 2016 by the scheduling of a drilling program from the Helix Q4000 at the Green Canyon 955 site in May 2017,

and the continued development of a comprehensive basic science program for broader evaluation of GOM gas hydrates in collaboration with the IODP through FY 2019 and/or FY 2020.

Ongoing work with the DOE National Laboratories continued to push the development of numerical simulation capabilities to accommodate emerging issues in reservoir heterogeneity and geomechanics, the validation of those tools through focused experimentation, and the contribution of numerical simulation in ongoing collaborations with Japan, India, and South Korea.

Finally, DOE and its research partners continued to disseminate research results to the scientific community during FY 2016 including through conferences, meeting presentations, and publication of a widely-read newsletter. The Program's funded research efforts also produced more than three dozen peer-reviewed publications in FY 2016 (Appendix B).

Information on the DOE Methane Hydrate Program, including detailed summaries of all active and completed projects and reports and publications resulting from DOE-funded investigations, are regularly updated and can be found at http://www.netl.doe.gov/research/oil-and-gas/methane-hydrates. Further information on the Program, including reports and activities of the Methane Hydrate Advisory Committee, are available at http://energy.gov/fe/science-innovation/oil-gas-research/methane-hydrate.

Appendix A: DOE Announces $3.8 Million Investment in New Methane Gas Hydrate Research

September 15, 2016 - 10:00 a.m.

The U.S. Department of Energy (DOE) has announced the selection of six multi-year research projects to receive $3.8 million in funding that will enhance the understanding of methane hydrate system behaviors when subjected to natural, environmental, or induced production-related changes, helping to determine both the production viability of a vast source of natural gas and to assess the role of gas hydrate in the larger global climate cycle.

The competitively selected projects will involve fundamental research assessing the scale, development, and nature of hydrate-bearing geological systems; the role of the systems in the natural environment; the potential of the systems for commercial recovery of methane; and the potential environmental implications of methane hydrate resource recovery. The research will involve laboratory, field, and numerical simulation studies of gas hydrate reservoir responses to production activities as well as natural variations.

Methane hydrate - natural gas trapped in ice-like cages of water molecules— represents a potentially vast energy resource. Methane hydrate occurs in both terrestrial and marine environments. It represents an important bridge fuel to a low-carbon energy economy. Recent discoveries of methane hydrate deposits in arctic and deep-water marine environments have highlighted the need for a better understanding of methane hydrate as a natural storehouse of carbon and a potential energy resource.

Since the passage of the Methane Hydrate Research and Development Act of 2000, the DOE has led a coordinated national methane hydrate research and development program in collaboration with six other federal and international agencies, universities, and industry. The program advances the scientific understanding of naturally occurring methane hydrate so that its resource potential and environmental implications can be fully understood.

The six new projects will be managed by the DOE Office of Fossil Energy's National Energy Technology Laboratory (NETL) and are described below. Funding amounts may vary as negotiations progress.

University of Rochester (Rochester, NY) – The University of Rochester will advance understanding of the environmental implications that methane leaking from dissociating gas hydrates could have on the ocean-atmosphere system. It will also enhance knowledge of the distribution and amount of methane emissions from the U.S. Atlantic Margin upper continental slope in the mid-Atlantic zone. DOE Funding: $887,836

University of Texas at Austin (Austin, TX) – The University of Texas at Austin will conduct a laboratory evaluation of the dynamic petrophysical attributes of gas hydrate–bearing sands in response to pressure reduction at macro- and micro-scale. This research will enhance

understanding of hydrate system behavior, improve the ability to simulate hydrate production, and make more realistic estimates of the ability of the hydrate resource to be a viable energy source. DOE Funding: $1,199,991

Louisiana State University (Baton Rouge, LA) – Louisiana State University will conduct a laboratory evaluation of the migration of fine-grained particles during gas production, with specific focus on factors unique to gas production from hydrate-bearing sediments. The research will guide DOE-funded reservoir modeling work on promising field sites as well as benefit hydrate production assessments by providing better understanding of the impact of fine grained sediments (within the overall sediment fabric) on hydrate system compressibility and permeability in sandy sediment. DOE Funding: $322,290

Texas A&M University Engineering Experiment Station (College Station, TX) – Texas A&M University will leverage prior NETL research and its own fieldwork data to study the fate of methane in water columns where hydrate shells form around methane bubbles in a process called hydrate bubble armoring. This effort will result in new analysis and improved models that will help to clarify hydrate's role in the global natural environment. DOE Funding: $361,533

The Regents of the University of California (La Jolla, CA) – The University of California at San Diego (Scripps Institution of Oceanography will assess controlled source electromagnetic (CSEM) technologies for locating marine hydrate deposits. Research will provide a fundamental understanding of the electrical properties of hydrate-bearing sediments and assess the usefulness of CSEM as a complementary technology for locating and characterizing gas hydrates. It will also contribute data at locations of known or suspected gas hydrate occurrence in the Gulf of Mexico. DOE Funding: $533,406

Texas A&M University Engineering Experiment Station (College Station, TX) – Texas A&M University advance the capabilities of a leading integrated model for hydrate system behavior. The research will increase understanding of deep oceanic and arctic hydrate deposits and will yield simulation capabilities useful in assessing and predicting production-related performance of hydrate deposits. DOE Funding: $731,414

The Office of Fossil Energy funds research, development and demonstration projects to reduce the risk and cost of advanced carbon technologies and further the sustainable use of the Nation's fossil resources. To learn more about the programs within the Office of Fossil Energy, visit our website or sign up for FE news announcements https://www.netl.doe.gov/business/solicitations. To learn more about the National Energy Technology Laboratory, visit the NETL website https://www.netl.doe.gov/.

Appendix B: FY 2016 Peer-Reviewed Publications

Boswell, R., Bunz, S., Collett, S., Frye, M., Fujii, T., McConnell, D., Meinert, J., Pecher, I., Reichel, T., Ryu, B-J., Shelander, D., Shin, K-S., 2016. Introduction to special section: exploration and characterization of gas hydrates. *Interpretation* **4** (1), SAi-SAii.

Boswell, R., Schoderbek, D., Collett, T., Ohstuki, S., White, M., Anderson, B., 2016. The Ignik Sikumi field experiment, Alaska North Slope: design, operations and implications for CO_2-CH_4 exchange in gas hydrate reservoirs. *Energy & Fuels*. **31** (1), 140-153

Boswell, R., Shipp, C., Reichel, T., Shelander, D., Saeki, T., Frye, M., Shedd, W., Collett, T., McConnell, D., 2016. Prospecting for Marine Gas Hydrate Resources. *Interpretation* **4** (1), SA13-SA24

Brothers, L., Herman, B., Hart, P., Ruppel, C., 2016. Subsea ice-bearing permafrost on the US Beaufort Margin: 1. Minimum seaward extent defined from multichannel seismic reflection data. *Geochem. Geophys. Geosys.* **17** (11), 4354-4365.

Coffin, R., Osburn, C., Plummer, R., Smith, J., Rose, P., Grabowski, K., 2015. Deep sediment-sourced contribution to shallow sediment organic carbon: Atwater Valley, Texas-Louisiana Shelf, Gulf of Mexico. *Energies* **8** (3), 1561-1583.

Constable, S., Kannberg, P., Weitemeyer, K., 2016. Vulcan: a deep-towed CSEM receiver. *Geochemistry, Geophysics, Geosystems* **17** (3), 1042-1064.

Daigle, H., 2016. Relative permeability to water or gas in the presence of hydrates in porous media from critical path analysis. *J. Pet. Sci. Eng.*, **146**, 526-535.

Daigle, H., Cook, A., Malinverno, A., 2015. Permeability and porosity of hydrate-bearing sediments in the northern Gulf of Mexico. *J. Marine and Petroleum Geology* **68**, 551-564.

Darnell, K., Flemings, P., 2015. Transient seafloor venting on continental slopes from warming-induced methane hydrate dissociation. *Geophysical Research Letters* **42** (24), 10765-10772

Frederick, J., Buffett, B., 2016. Submarine groundwater discharge as a possible formation mechanism for permafrost-associated gas hydrate on the circum-Arctic continental shelf. *J. Geophysical Research-Solid Earth.* **121** (3), 1383-1404.

Hillman, J., Cook, A., Sawyer, D., Kucuk, H., Goldberg, D., 2016. The character and amplitude of bottom simulating reflections in marine seismic data. *Earth and Planetary Science Letters* **459**, 157-169.

Jaiswal, P., 2016. Hydrate quantification: integrating full-waveform inversion, seismic attributes, and rock physics. Interpretation **4** (1), SA55-SA71.

Jang, J., Santamarina, C., 2016. Hydrate bearing clayey sediments: formation and gas production concepts. *J. Mar. Pet. Geo.*, **77**, 235-246.

Lorenson, T., Grienert, J., Coffin, R., 2016. Dissolved methane in the Beaufort Sea and the Arctic Ocean, 1992-2009; sources and atmospheric flux. *Limnology and Oceanography* **61**, S300-S323.

Mahabadi, N., Dai, S., Seol, Y., Yun, T., Jang, J., 2016. The water retention curve and relative permeability for gas production from hydrate-bearing sediments: pore-network model simulation. *Geochem. Geophys., Geosys.*. **17** (8), 3099-3110.

Mahabadi, N., Zheng, X., Jang, J., 2016. The effect of hydrate saturation on water retention curves in hydrate-bearing sediments. *Geophys. Res. Lett.* **43** (9), 4279-4287.

Majumdar, U., Cook, A., Shedd, W., Frye, M., 2016. The connection between natural gas hydrate and bottom-simulating reflectors. *Geophys. Res. Lett.* **43** (13), 7044-7051.

Malinverno, A., Goldberg, D., 2015. Testing short-range migration of microbial methane as a hydrate formation mechanism: results from Andaman Sea and Kumano Basin drill sites and global implications. *Earth and Planetary Science Letters* **422**, 105-114.

Marlow, J., Skennerton, C., Li, Z., Chourney, K., Hettich, R., Pan, C., Orphan, V., 2016. Proteomic stable isotope probing reveals biosynthesis dynamics of slow growing methane based microbial communities. *Frontiers in Microbiology* **7**: 563.

Miller, J., Agena, W., Haines, S., Hart, P., 2016. Processing of multichannel seismic reflection data acquired in 2013 for seismic investigations of gas hydrates in the Gulf of Mexico: *U.S. Geological Survey Open-File Report* **2016–1037**, 32 p., http://dx.doi.org/10.3133/ofr20161037.

Myshakin, E., Ajayi, T., Anderson, B., Seol, Y., Boswell, R., 2016. Numerical simulations of depressurization-induced gas production from gas hydrates using 3-D heterogeneous models of L-pad, Prudhoe Bay Unit, North Slope Alaska. *J. Nat. Gas Sci. & Eng.* **35**, 1336-1352.

Nole, M., Daigle, H., Cook, A., Malinverno, A., 2016. Short-range, overpressure-driven methane migration in coarse-grained gas hydrate reservoirs. *Geophys. Res. Lett.* **43** (18) 9500-9508

Peszynska, M., Medina, F., Hong, W., Torres, M., 2016. Reduced numerical model for methane hydrate formation conditions of variable salinity: time-stepping variants and sensitivity. *Computation* **4** (1),

Philip, B., Denny, A., Solomon, E., Kelley, D., 2016. Time series measurements of bubble plume variability and water-column methane distribution above southern Hydrate Ridge, Oregon. *Geochemistry, Geophysics, Geosystems* **17** (3), 1182-1196.

Prouty, N., Sahy, D., Ruppel, C., Roark, E., Condon, D., Brooke, S., Ross, W., Demopoulos, A., 2016. Insights into methane dynamics from analysis of authigenic carbonates and chemosynthetic mussels at newly-discovered Atlantic Margin seeps. *Earth Planetary Science Letters* **449**, 332-344.

Ruppel, C., Herman, B., Brothers, L., Hart, P., 2016. Subsea ice-bearing permafrost on the US Beaufort Margin: 2. Borehole constraints. *Geochem. Geophys., Geosys.* **17** (11), 4333-4353.

Scandella, B. P., Pillsbury, L., Weber, T., Ruppel, C., Hemond, H. F., and Juanes, R., 2016. Ephemerality of discrete methane vents in lake sediments. *Geophys. Res. Lett.*, v. 43, pp. 4374-4381.

Schindler, M., Batzle, M., Prasad, M., 2016. Micro X-Ray computed tomography imaging and ultrasonic velocity measurements in tetrahydrofuran-hydrate-bearing sediments. *Geophysical Prospecting.*

Weinstein, A., Navarette, L., Ruppel, C., Weber, T., Leonte, M., Kellerman, M., Arrington, E. Valentine, D., Scranton, M., Kessler, J., 2016. Determining the flux of methane into Hudson Canyon at the edge of methane clathrate hydrate stability. *Geochem, Geophys, Geosys.* **17** (10), 3822-3892.

Yonkofski, C., Horner, J., White, M., 2016. Experimental and numerical investigation of hydrate-quest molecule exchange kinetics. *J. Natural Gas Sci. Eng.*, **35** (B), 1480-1489.

You, K., DiCarlo, D., Flemings, P., 2016. Impact of gravity on hydrate saturation in gas-rich environments. *Water Resources Research* **52** (2), 1265-1285.