U.S. Department of Energy • Office of Fossil Energy • National Energy Technology Laboratory

# Fire in the Ice

S l i+ 5) Fpp+ 0 Methane Hydrate Newsletter

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## Changing Perspectives on the Resource Potential of Methane Hydrates

*Ray Boswell, U.S. Department of Energy, National Energy Technology Laboratory*
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For the past 20 years, methane hydrate has been one of the most tantalizing prospects in the realm of future unconventional energy supplies. In 2000, the U.S. Congress accelerated the nation's hydrate R&D effort by authorizing the Methane Hydrate Research and Development Act (MHR&D Act). This legislation substantially increased funding and directed the U.S. Department of Energy, the U.S. Geological Survey (USGS), the Minerals Management Service (MMS), the National Oceanic and Atmospheric Administration (NOAA), the Naval Research Lab (NRL), and the National Science Foundation (NSF) to work together to uncover the physical nature, economic potential, and environmental role of naturally-occurring methane hydrates. On August 8, the President signed the Energy Policy Act of 2005, which includes re-authorization of the MHR&D Act for another 5-year installment. This article briefly outlines the developments in hydrates R&D over the five years since the implementation of the Act. These developments will guide future efforts and have served to bring the resource potential of methane hydrates into clearer focus.

*Gas hydrate-bearing sediment core from the Mallik site, Northwest Territories, Canada.*

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**This newsletter is available online at www.netl.doe.gov/scngo/NaturalGas/hydrates/index.html**

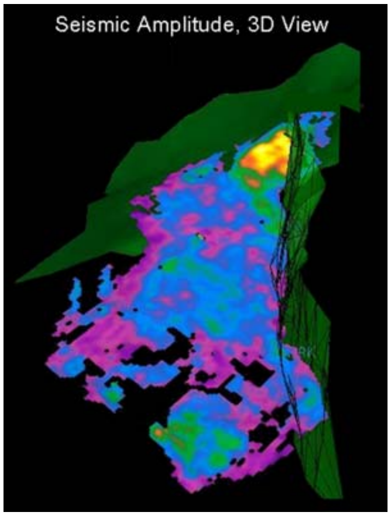
**Interested in contributing an article to *Fire in the Ice*?**

This newsletter now reaches nearly 500 scientists and other individuals interested in hydrates in sixteen countries. If you would like to submit an article about the progress of your methane hydrates research project, please contact Karl Lang at 703 891-4813 (klang@hartenergy.com)

***From stability zones to petroleum systems –*** It is now clear that natural methane hydrate systems, like virtually all petroleum systems, are highly complex and heterogeneous entities. Based on work with Mallik samples, researchers now understand that, due to complex changes in pore water chemistry during hydrate formation, deposits well above the hypothetical "base of the stability zone" can be very close to the phase boundary. In fact, instead of a single phase boundary, there is a broad zone across which dissociation can occur. Similarly, work in the Gulf of Mexico and elsewhere has shown that we can no longer envision marine hydrates as broad, disperse, continuous and low-level accumulations within uniform stability zones. Instead, the hydrate stability zone is now documented as having a very complex geometry, with major perturbations due largely to vertical and lateral changes in pore water salinity and heat flow associated primarily with salt tectonics. Some of these local changes may well be driven by variable and vertical fluid fluxes. Furthermore, it is evident that within these zones, the actual occurrence of hydrate will be sporadic, controlled not only by pressure, temperature and chemical conditions, but also by many of the same parameters that industry has been using for decades to explore for more conventional resources. The most important of these parameters are source (sufficient supplies of both water and gas), and reservoir (containers of necessary quality to allow the formation and significant concentration of hydrate). Therefore, hydrate exploration must include a search for the convergence of those conditions that not only enable hydrate to form, but also that can concentrate it into deposits of significant richness.

***Hydrates are technically producible from reservoir systems –*** Concepts for methane production from hydrate initially included sediment "mining" and other exotic ideas. However, work conducted by the Mallik 2002 gas hydrate production research well program has shown that production of methane from hydrates at meaningful rates should be possible through tailoring of already existing well-based technologies. For sandstone reservoirs with bounding shales (either in permafrost or marine settings), initial production tests are likely to feature depressurization, augmented as necessary by timely and focused thermal stimulation. Further long-term production testing, under a variety of reservoir conditions, is now needed to determine the rates obtainable and the most effective approaches to production.

***Hydrate exploration beyond BSRs –*** For much of the history of hydrate R&D, the primary tool for assessing the occurrence of hydrates in marine environments was the presence of bottom-simulating reflectors (BSRs; attributed to a phase transition from hydrate to free gas and water with depth) and other anomalous features (such as amplitude "blanking") on 2-D seismic reflection profiles. Today, it is widely accepted that the presence or absence of a BSR provides little information on the distribution or concentration of hydrate. Therefore, geophysicists are turning their attention to the use of advanced seismic techniques as a means to directly detect hydrate within the strata between the BSR and the sea floor. Advanced processing techniques with industry standard 3-D data sets, as well as multi-component ocean-bottom seismic data where available, are showing great promise at detecting the subtle mechanical property changes in sediments with sufficient hydrate concentration. Researchers working in association with the DOE, the USGS, and BP Exploration, Alaska, have applied 3D-seismic, conventional well log data, and advanced numerical simulation to identify more than a dozen unique, delineated, and potentially-drillable hydrate prospects within the area of the Milne Point Unit on the Alaskan North Slope. Therefore, for the first time, hydrate researchers can talk of hydrates "prospects" and "recoverable volumes"–terms previously restricted to more established gas resource elements.




*A 3-D seismic amplitude view that depicts a gas hydrate prospect within a fault-bounded trap within the Milne Point Unit on the Alaska North Slope.*

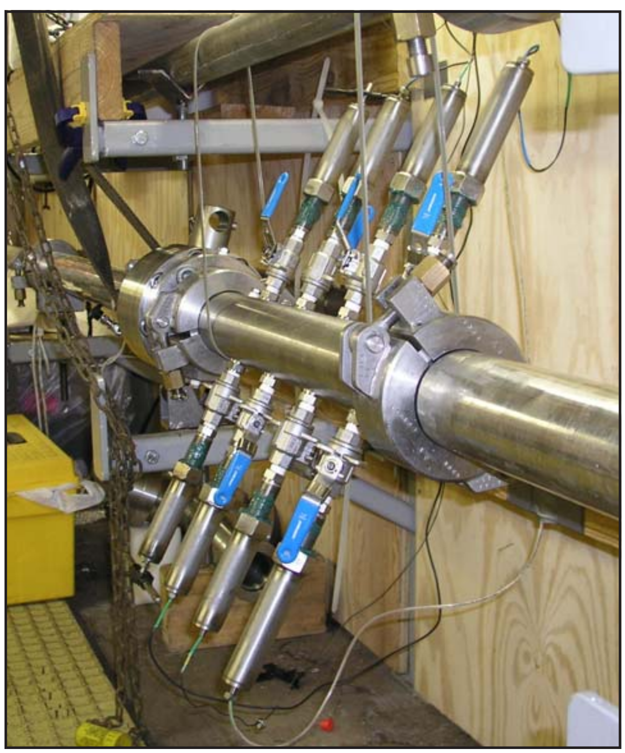
***A common focus on the reservoir –*** Over the past decade, a common view (informed largely by sampling bias that concentrated most early findings at the Mallik site and on the Blake Ridge) has divided hydrates into two apparently distinct classes; marine hydrates (low-level concentrations in muds) and permafrost (or Arctic) hydrates (high-level concentrations in sandstone). However, as evidenced by the initial results at Nankai, there is clearly no geological inhibition on sandstone occurrence in the shallow sediments of the deep-water environment. Although the vast majority of the total mass of marine hydrate may indeed be encased in shales, that volume does not necessarily represent the marine hydrate resource potential. Initially, at least, the pursuit of hydrate in the deep ocean will proceed in the same way as it will in the Arctic, by seeking out the quality sandstone reservoirs that are needed not only to enable hydrate to form in meaningful scales and concentrations, but also to provide the potential for extraction at viable rates.

***A growing role for numerical simulation –*** The ability to numerically simulate the behavior of hydrate reservoirs under natural conditions has improved substantially over the past five years, and will be critical to conducting efficient field and laboratory studies going forward. (Note: The accompanying article in this issue provides the latest news regarding the ongoing development and validation of the leading hydrate reservoir simulators.)

*The Mallik 2002 Gas Hydrate Production Research Well Program was a landmark in hydrates R&D*

***Bringing Nature to the lab (and the lab to Nature) –*** Perhaps the biggest challenge in conducting methane hydrate research is preserving natural samples for study because methane hydrate is not stable at normal sea-level conditions. A major advance in hydrate R&D, first accomplished in the Integrated Ocean Drilling Program's Leg 204, has been the increasing ability to collect samples at sea and preserve them at *in-situ* pressure for transportation to the laboratory. Just this spring, another milestone was achieved in the Gulf of Mexico during the JIP drilling project (see related article in this issue) when a sample was transferred from a pressure core barrel into a pressurized chamber designed to allow measurement of certain physical properties, without the core material ever coming out of conditions of hydrate stability. While these are two examples of success, there are many more improvements to make to allow future cruises to sample the wide range of environments that will be necessary to make these measurements more representative of natural hydrate environments.

In addition, an increasing array of sophisticated new tools and technologies are being brought to bear on the study of these samples. For example, scientists at the Pacific Northwest National Lab and the Lawrence Berkeley National Lab are using non-destructive technologies such as resident ultrasound spectrometry and computed tomography (CT) x-ray scanning to look inside hydrate/sediment samples and study the three-dimensional details of ongoing hydrate dissociation. In addition to new tools and better samples, lab scientists are also homing in on measurement of the most critical properties related to hydrate's resource potential. For example, lab work is now moving beyond characterizing methane hydrate in steady state conditions to studying: 1) how temperature and pressure changes will propagate through a hydrate reservoir, 2) how easily liberated gas and water can flow in response to these changes, and 3) how the reservoir's mechanical stability might be impacted and further complicate fluid flow.



*This device, constructed by Georgia Tech in association with the GOM JIP, enabled the first physical property measurements to be made on a deep-sea hydrate core consistently maintained at* in-situ *pressures.*

***Recreating Nature in the lab –*** Because of the difficulties in recovering and studying natural samples, laboratory experiments are becoming much better at synthesizing samples and developing procedures that more closely replicate natural conditions. For example, newly-developed and continually-improving pressure cells such as the Oak Ridge National Lab's Sea-Floor Process Simulator, USGS's GHASTLI device and Brookhaven National Lab's FISH, are allowing scientists to replace analogue materials or bulk samples of synthesized hydrate with more representative hydrate-sediment mixtures. There are on-going studies to determine the best way to make hydrate-sediment mixtures in the lab that are most representative of the conditions found in nature. As with studies of natural samples, laboratory studies are also evolving from characterizing samples in a steady-state environment to understanding the rate and consequences of changes to the hydrate during changes in pressure, temperature and fluid flow.

***Clarifying the volume of technically recoverable resource –*** For the past decade, the methane hydrate issue has been framed by incredibly large global gas-in-place estimates. For purposes of understanding global climate and the global carbon cycle, such in-place numbers will continue to be relevant; however, for the issue of resource potential, in-place numbers are less useful. Beginning with an ongoing effort by the MMS in the Gulf of Mexico and other Outer Continental Shelf areas, and continuing with work on the Alaska North Slope by the USGS, the DOE, and others, we are now beginning to see the first attempts to estimate both technically-recoverable (TRR) and economically-recoverable resources (ERR) of methane in hydrate. As these new estimates arrive, they will necessarily be lower than the prevailing in-place numbers. However, whatever loss of impact occurs due to a reduction of the "big numbers" is more than offset by the increased reliability and relevance of the smaller technically recoverable numbers. Clearly, as we go forward, scientists and policy makers alike will be able to better assess what is at stake with methane hydrate R&D.

Through a half-decade of laboratory and fieldwork, we now know much more about methane hydrate, both as a physical substance, and as a constituent of the natural environment. We are now confident that production, at potentially viable rates, is technically feasible under certain conditions. Extending that feasibility to include a broader range of conditions will clearly be a significant challenge. We still have not confirmed the scale of the potentially recoverable share of the in-place resource, particularly in the marine setting. We still do not have proven means of accurately detecting and appraising marine accumulations through remote sensing. And there is much work to do on testing and refining the technologies that will be used to produce hydrate. Mallik provides only one point on the experience curve of turning gas hydrates into a viable energy resource.

Nonetheless, the work accomplished under the five years of the MHR&D act has left us well positioned to effectively address these challenges. A new appreciation for the complexities of natural hydrates is a key step in moving to a more complete understanding that incorporates standard industry concepts such as petroleum systems, prospects, and recoverable resources. Once relegated to pie-in-the-sky status, the addition of methane hydrate to the nation's, and the world's, energy portfolio is moving closer to reality.

# An International Effort to Compare Methane Hydrate Reservoir Simulators

*By The Methane Hydrate Simulator Comparison Team (see list at end of article)*

The National Energy Technology Laboratory (NETL) and the U.S. Geological Survey (USGS) are guiding a collaborative, international effort to compare methane hydrate reservoir simulators. The intentions of the effort are: (1) to exchange information regarding gas hydrate dissociation and physical properties enabling improvements in reservoir modeling, (2) to build confidence in all the leading simulators through exchange of ideas and cross-validation of simulator results on common datasets of escalating complexity, and (3) to establish a depository of gas hydrate-related experiment/production scenarios, along with the associated predictions of these established simulators that can be used for comparison purposes.

Numerical modeling of gas hydrate reservoir system behavior in natural settings is an increasingly critical element in the effort to realize the production potential of methane hydrate. The proper application of carefully tested simulators will support the development of safe and efficient production technologies, help to fully appraise the results obtained from both laboratory experiments and field production tests, and assist in the design and regional layout of future development wells. To meet this critical need and facilitate current and future model development, the authors formed an international team to conduct a comparison of methane hydrate simulators.

## A Number of Models Have Been Developed

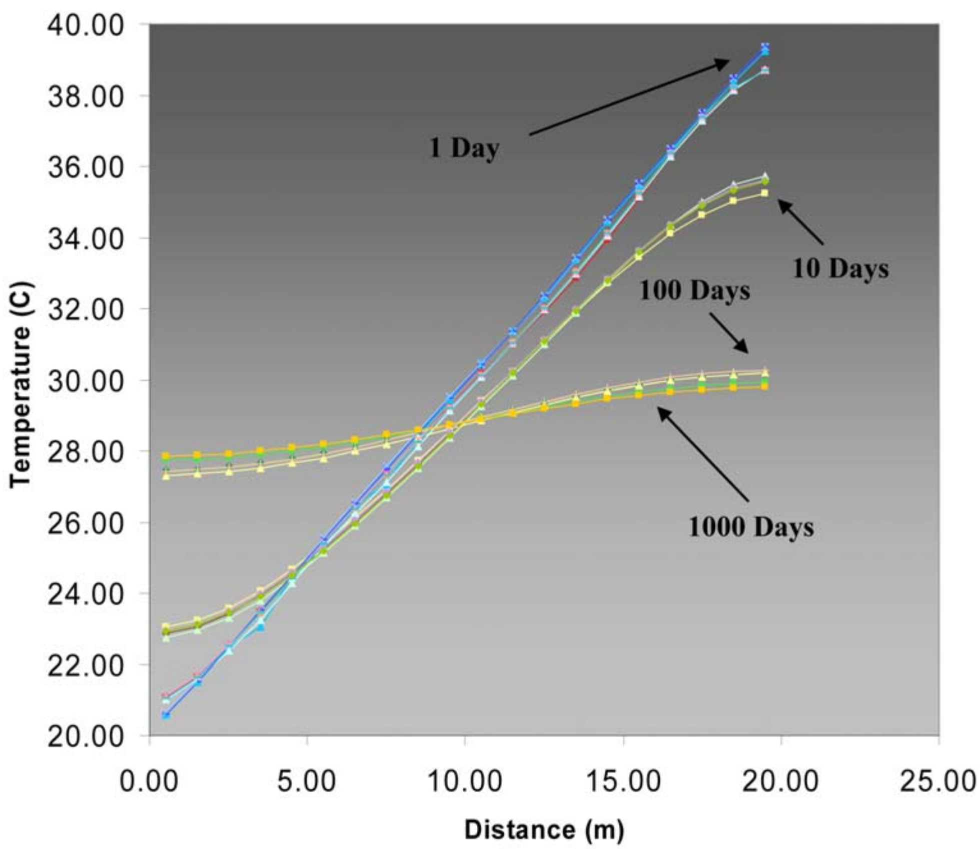
Lawrence Berkeley National Laboratory, with support from NETL, developed the first publicly available model designed exclusively to simulate gas hydrate reservoir behavior and production potential, TOUGH-FX/Hydrate. Further information about the TOUGH family of codes can be found at http://esd.lbl.gov/TOUGH2. In addition, NETL will soon release a freeware, open-source, earlier version of the code under the name HydrateResSim. This open-source version of the code will be available for use as-is from the NETL website, and in addition NETL will provide a limited level of user support, potentially including the development of future updates based on modifications made and/or suggested by users of the code.

In addition to these codes, other groups have developed simulators based on widely differing approaches to gas hydrate simulation. For example, MH-21 Hydrate Reservoir Simulator, MH-21 HYDRES, developed by the National Institute of Advanced Industrial Science and Technology, Japan Oil Engineering Co., Ltd. and the University of Tokyo, has been specifically designed to assess production from gas hydrate deposits. Further information concerning the MH-21 research consortium can be found at http://www.mh21japan.gr.jp/english/. The Pacific Northwest National Laboratory and the Petroleum Engineering Department at the University of Alaska, Fairbanks have modified the multi-phase simulator (STOMP) to allow for the inclusion of gas hydrates, STOMP-HYD. Further information about STOMP can be found at http://stomp.pnl.gov. Also, those investigating Alaska North Slope gas hydrate resource potential as part of a BP Exploration Alaska, Inc. (BPXA) research project in collaboration with the US Department of

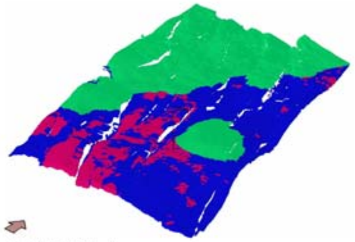
Energy, have extended work begun at the University of Calgary and the University of Alaska-Fairbanks to apply a commercially available simulator (CMG STARS) to model production from characterized gas hydrate-bearing reservoirs. In addition to these more comprehensive and mature efforts, numerous other groups have developed their own simulators for use on specific laboratory- and field-based gas hydrate experiments and characterizations.

## Various Models Utilize Different Approaches

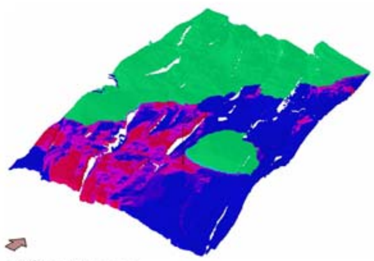
Simulation of gas hydrate reservoir production involves solution of a complex combination of highly coupled fluid, heat, and mass transport equations combined with the potential for formation and/or disappearance of multiple solid phases in the system. Also, the physical and chemical properties of the geologic media containing gas hydrate are highly dependent on the amount of gas hydrate present in the system at any given time. Gas hydrate modelers have used many different conceptual models and mathematical algorithms to solve these problems; each approach has certain advantages and disadvantages but none is either completely accurate or proven reliable from first principles. Given the wide range of differing approaches taken by the various groups developing simulators, this international code comparison effort is the first attempt to explore and understand the impacts of these modeling assumptions on production scenarios involving gas hydrates.



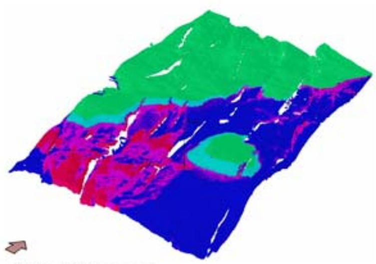

*A comparison of model predictions of temperature distribution using HydrateResSim, MH21 HYDRES, CMG STARS, STOMP-HYD, and TOUGH-FX/Hydrate to test basic heat and mass transfer in the models. The temperature profiles have been plotted for each model as a separate trace for each of four times.*



Initial State



After 7 years



After 15 years

*A 15-year time series of saturations resulting from the use of CMG STARS to model dissociation response to depressurization of free gas adjacent to a gas hydrate deposit (Dark blue is water, green is gas hydrate, red is free gas). After 15 years, the original free gas is produced and a "halo" zone of partially gas saturated water-bearing reservoir has appeared where gas hydrates have dissociated. The ultimate goal of the comparison study is to explore the relative performance of a suite of such simulators on similar complex problems.*

## Results Will Be Available Online

The suite of problems for the comparison exercise is currently under development. It will begin with a non-gas hydrate case to test basic mass and heat transfer capabilities in the codes, and then progress through gas hydrate-containing problems of increasing complexity, with the final problem expected to be the consideration of a reservoir simulation designed around actual reservoir data obtained from BPXA/NETL research in collaboration with the USGS.

The results of the comparison study, including detailed scenario definitions and model outputs, will be made available to the methane hydrate R&D community through the NETL methane hydrate web site (http://www.netl.doe.gov/scngo/NaturalGas/hydrates/index.html). To obtain more information about this study, please contact Joe Wilder (joseph.wilder@netl.doe.gov) or Kelly Rose (kelly.rose@netl.doe.gov).

**The analytical team working on this effort includes:**

Timothy Collett (U.S. Geological Survey)

Robert Hunter (ASRC Energy Services; BP Exploration Alaska, Inc.)

Masanori Kurihara (Japan Oil Engineering Co., Ltd.)

Yoshihiro Masuda (The University of Tokyo)

Pete McGrail (Pacific Northwest National Laboratory)

George Moridis (Lawrence Berkeley National Laboratory)

Hideo Narita (National Institute of Advanced Industrial Science and Technology)

Mark White (Pacific Northwest National Laboratory)

Joseph W. Wilder (National Energy Technology Laboratory)

Scott Wilson (Ryder Scott Company, Petroleum Consultants)

# Joint Industry Project (JIP) Gulf of Mexico Gas Hydrate Coring Update

*By George Claypool, Chief Scientist*

This spring, scientists, engineers and marine personnel from universities, government agencies and private companies collaborated during a 35-day expedition to drill, log, and core gas hydrate-containing sediments in the Gulf of Mexico. The semisubmersible drilling vessel, *Uncle John*, was used for this important component of a 4-year project funded by the ChevronTexaco Gulf of Mexico Gas Hydrates Joint Industry Program (JIP) and the Department of Energy. Two deep-water regions—Atwater Valley and Keathley Canyon—had been selected as targets for this expedition, based on analysis of seismic surveys and sea floor coring programs carried out during previous phases of the JIP.

The main objective of the JIP cruise was to collect sediment cores and a full suite of well logs on seismically well-characterized sediments that showed evidence for occurrence of gas hydrates. Although the petroleum industry has operated in the Gulf for decades, relatively little information has been collected on the nature of the shallow sediments, and seismic records and well logs have not been calibrated for the interpretation of gas hydrates. Results from the JIP cruise are providing improved capability to predict and control potential hazards that gas hydrates pose to deep-water drilling operations.

The data collected at the two drill site locations is being used to ground truth predictions based on the pre-cruise seismic analysis. Preliminary analysis of the logs and pressure cores obtained indicates that there is general agreement between the pre-cruise predictions and the actual measured values of hydrate occurrence and concentration. During the cruise, either logging-while drilling (LWD) or conventional wireline logging was successfully conducted in four separate boreholes. The presence of gas hydrates in the sediments and cores collected from these areas during the JIP cruise was indicated by the logging-while-drilling responses and analyses of pore waters, and confirmed by pressure core outgassing experiments. In one case, the wellbore apparently encountered a fracture-controlled gas hydrate occurrence.


*Nightime core recovery during the JIP Gulf of Mexico cruise.*

## First Wells Drilled in Atwater Valley

The ship arrived at the first site and was ready to begin operations in the early morning hours of April 19. The *Uncle John* deployed a remotely operated vehicle (ROV) to the seafloor to place positioning beacons and collect short push cores of the surface sediments. The ROV allows remote viewing and manipulation of equipment on the seafloor, a capability critical to the drilling and coring operations undertaken during the cruise.

Atwater Valley 13-1 spudded as a logging-while-drilling (LWD) hole just before midnight on April 19. Approaching depths of 220 meters beneath the seafloor (mbsf) the hole became increasingly tight on pipe connections. Log quality began to deteriorate due to hole washout and drilling was terminated. However, the log data obtained in AT13-1 is of high quality, with about 80% of the hole within gauge. AT13-1 was a "reference site" chosen to permit investigation of relatively undisturbed sediment between two diapiric features expressed as topographic mounds on the seafloor. Diapiric structures provide conduits for expulsion of heat, fluids and sediment from deeper in the subsurface. The logs are consistent with a fine-grained, clay-dominated sequence. There are a few thin zones with elevated resistivity, interpreted to be possible gas hydrates or lower salinity pore water.

Once work at AT13-1 was complete, the hole was abandoned in accordance with the MMS drilling permits. From AT13-1 the *Uncle John* moved a short distance to the location of AT14-1, a second LWD hole on the flank of the major diapiric feature (referred to in the site surveys as Mound F). The feature is capped by a seismic amplitude anomaly at a depth of about 30 meters subbottom, believed caused by free gas. AT14-1 penetrated fine-grained clay dominated sediments above the side of the feature, with no apparent sand units. The logs indicated lower formation resistivity compared with the AT13-1 hole, probably due to increased pore water salinity. An abrupt shift to lower formation density and resistivity occurs at a depth of about 180 mbsf, the depth at which the intrusive feature had been mapped on seismic. The log-derived bulk density measurements from AT14-1 were used to calculate sediment porosities ranging from about 58 to 55 percent. The resistivity tool indicates several thin, high-resistivity zones within the depth interval 18-78 mbsf in the AT14-1 well, suggesting the possible occurrence of gas hydrate.

*Prepared core retrieved from AT13-2*

## Cores Show Indications of Hydrate

The *Uncle John* then moved back to the previous Atwater Valley Block 13 location to begin coring at AT13-2. Initial attempts at coring were plagued by a number of problems and delays: failures occurred with the drilling and coring tools, wind and currents made it difficult to keep the drill ship on station, and the nature of the sediment was such that it became difficult to keep the borehole open during core retrieval. Coring ended on April 30$^{th}$, and attempts to conduct wireline logging in the cored hole were unsuccessful due to collapse of the hole. Unfortunately, while preparing to abandon AT13-1, the seabed frame used to direct the drill string fell to the seafloor and its recovery resulted in additional lost time.

The core material that was collected showed that the sediment at AT13-1 consists of a soft, fine-grained and homogeneous green-gray clayey-silt with numerous gas expansion features below depths of about 7 meters beneath the seafloor. There is a broad salinity minimum extending over the 7-30 m depth interval that could have been caused by fresh water from decomposed gas hydrate. However, there was no direct evidence for gas hydrate occurrence in the cores at AT13-1.

Because of schedule constraints and the lost time, the deep coring planned for AT14-2 was cancelled and the remaining two days available at the Atwater Valley location were spent on planned shallow coring at Mound F, where gas hydrates had been previously recovered in shallow piston cores. Two holes, ATM1 and ATM2, were cored on top of the mound to depths of 30 meters beneath the sea floor. The Mound sediments were dark-gray silty clays with textures described as mousse-like or soupy, with the sulfate-methane interface very close to the seafloor. Pore water salinities were high —56 parts-per-thousand (ppt) — with some distinct lower salinity zones (51 ppt) suggesting that gas hydrate was present but dissociated during the time (~45 min.) required

*Cataloging core in the onboard lab*

for core retrieval and processing. A pressure core was successfully collected from a depth of 27 mbsf and transferred to a storage chamber for X-ray and core logging. A subsequent degassing experiment confirmed the presence of gas hydrate suggested by the core imaging and logging data. These experiments indicated that hydrates were present in the identified part of the core at an average level of about 3% of pore volume.

## Second Stage of Cruise at Keathley Canyon

The Uncle John arrived at Keathley Canyon on May 7, twenty days into the thirty-five day schedule. The site planned and permitted as KC151-1 was not drilled. The ROV was used to take bottom water samples and shallow (0-1 m) push cores while preparing for drilling the next LWD hole, KC151-2. The well was spudded on May 8 and drilled to a total depth of 460 mbsf. LWD gamma ray measurements suggest that the KC 151-2 borehole penetrated mostly a fine-grained clay dominated sedimentary section, except for one sand section at 95-110 mbsf. There are also several relatively sand-rich sections deeper in the well near 140 and 150 mbsf. The most significant feature of KC 151-2 is the high resistivity interval within the section from about 220 mbsf to 300 mbsf, which probably indicates the occurrence of gas hydrates. Resistivity-at-bit (RAB) images from this high resistivity interval also reveal the presence of numerous steeply dipping (82 plus degrees) fractures throughout this section. A subtle resistivity response within the interval 371-392 mbsf occurs at the expected depth of the bottom-simulating reflection (inferred from seismic at 385 mbsf).

Following completion of KC151-2 and removal of the drill pipe and logging tools, the coring assembly was lowered to begin coring KC151-3, where selective coring focused on the depth intervals 0-45, 100-103,

*Transferring core to the lab*

and 210-390 mbsf. Cores recovered from KC151-3 contained the usual greenish-gray mud with visible parting due to gas exsolution at depths greater than about 8 mbsf, the depth of the sulfate-methane interface. No visible gas hydrates were recovered in the non-pressurized cores from KC151-3, but two successful pressure cores contained methane quantities indicative of gas hydrate saturations of about 6% and 1.5% at depths of 236 and 383 mbsf, respectively. Coring concluded on May 18 and wireline logging operations and a vertical seismic profile experiment in KC151-3 were successfully conducted on May 19. Samples and equipment were packed for shipping during the transit to Galveston, where the cruise ended on the morning of May 22, 2005.

## Summary of Results

The downhole log data from all four LWD wells surveyed showed some evidence of gas hydrates. Log data from the two Atwater Valley wells shows little evidence of significant gas hydrate occurrences, other than several thin, possibly stratigraphically controlled, gas-hydrate-bearing intervals. The data from these wells further suggests the presence of a complex pore water fluid regime, with variable well log-inferred pore water salinities.

The most notable characteristic of the Keathley Canyon 151-2 well is a high resistivity interval within the section from about 220 mbsf to 300 mbsf, which probably indicates the occurrence of gas hydrates. As mentioned earlier, LWD-derived resistivity-at-bit images from this high resistivity interval also reveal the presence of numerous steeply dipping gas-hydrate filled fractures throughout this section. Resistivity log-derived gas hydrate saturations (percent of pore space occupied by gas hydrate) range from 20-30 percent. The well logs and core data collected in Keathley Canyon were in general agreement with the pre-cruise seismic analysis. The well log data from the Keathley Canyon 151-2 well again shows that the occurrence of gas hydrates is influenced by the character of the sediments. In the case of Keathley Canyon, the borehole apparently encountered a fractured-controlled gas hydrate occurrence.

Operationally, the cruise enabled the testing of several critical sampling and analysis tools. It is clear that pressure coring technology needs additional refinement, with careful tailoring of tools to conditions. In addition, the cruise marked the use of a new analysis device that allowed, for the first time ever, the measurement of critical hydrate-sediment physical properties on samples that had never been removed from in-situ pressures. While only limited experiments were conducted, the device, manufactured at Georgia Tech, indicated the importance of measurements made on cores that have never been depressurized.

The JIP has added to our knowledge of gas hydrates in the GOM and is currently completing postcruise lab work and analysis. Much more needs to be done in the areas of seismic prediction, effects of fluid flux, and geologic setting on gas hydrate occurrence. Continued improvement in pressure collection and measurement equipment will result in more accurate charaterizaton of gas hydrates.

The members of the JIP will be meeting this Fall to further integrate and assess the cruise's findings, and develop recommendations for potential further activities. Please visit a special session of the American Geophysical Union meeting this December that will be dedicated to JIP activities to learn more about this project (see the Announcements section of this issue).

## USGS Provides DVD Archive of Raw Bottom Photos from Gulf of Mexico Research Cruise

The United States Geological Survey, in cooperation with the U.S. Department of Energy, conducted a June 2004 research cruise in the northern Gulf of Mexico to study seafloor ecosystems proximal to methane hydrate accumulations. Drilling is not allowed near these seafloor communities without waivers from the Minerals Management Service (MMS). Understanding the distribution of these ecosystems is, therefore, essential for safety and permitting purposes. The archive can be accessed from a link on the NETL Hydrates website, or directly from the USGS at http://woodshole.er.usgs.gov/openfile/of2004-1285/. Its full title and reference info is: Archive of Raw Bottom Photographs Collected During Cruise P1-04-GM, Northern Gulf of Mexico, 21-24 June, 2004. USGS Open-File Report 2004-1285 by John Evans, Dan Fornari, Lauren Gilbert, Mike Boyle, Jennifer Dougherty, and Deborah R. Hutchinson.

## USGS Workshop Addresses Integration of Hydrate Laboratory and Modeling Activities

The U.S. Geological Survey convened a small workshop on 2-3 August, 2005, to identify how its gas hydrate laboratory studies could be more closely aligned with a growing number of modeling studies. The salient recommendations arising from the 29 workshop participants can be grouped into five research directions: 1) measurement of transient and time-dependent processes in the natural gas hydrate reservoir systems (i.e., changes in environmental conditions, including changes in geomechanical response, fluid flow, formation permeability, dissociation rates, and thermal properties; 2) improved understanding of how current lab-core-logging measurements represent in-situ natural conditions (i.e., determining how representative measurements are on either natural samples that have come out of the stability zone prior to analysis or on synthetic hydrate sediment mixtures that are made in water-limited or gas-limited experiments) ; 3) targeted basic characterization at laboratory and field scales for specific properties (e.g., thermal properties at reservoir pressures and temperatures, properties of fine-grained, low-hydrate saturation systems); 4) support for the code-comparison study on gas-hydrate-reservoir models currently underway at DOE, including developing datasets based on well-constrained field and laboratory experiments; and 5) more well-documented field-based gas-hydrate production tests. Please contact Deborah Hutchinson (dhutchinson@usgs.gov) at the USGS for more information on the results of this workshop.

## Three Methane Hydrate Sessions Scheduled for AGU Fall Meeting

The American Geophysical Union Fall Meeting, to be held in San Francisco on December 5th through the 9th, is expected to draw a crowd of over 11,000 geophysicists from around the world. This year, the agenda will include three special sessions related to methane hydrates:

*C02: Intrapermafrost Gas Hydrates and Their Relationship to Geohazard and Global Climate Change,* convened by Scott Dallimore, Tim Collett, and Bill Winters;

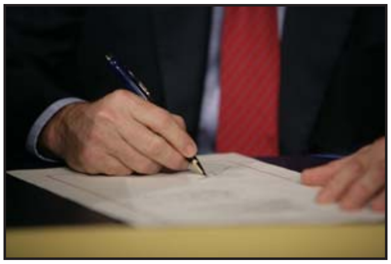
*OS14: Methane Hydrates at Gulf of Mexico JIP Sites: Drilling and other results,* convened by Warren Wood and George Claypool, intended for results of the ChevronTexaco Gulf of Mexico Gas Hydrates Joint Industry Project JIP drilling earlier this spring, and supporting work; and

*OS15: Natural Gas Hydrates; Modeling, Laboratory, and Field Investigations,* convened by Pat Hart and Warren Wood, intended for results not related to either the JIP drilling or permafrost gas hydrates.

Links to descriptions of each of these sessions may be found at http://www.agu.org/meetings/fm05 using the program search tool and the codes shown above with each title.

## IODP Expedition Leg 311 Underway

The Integrated Ocean Drilling Program is currently conducting scientific drilling on the Cascadia Margin, offshore Vancouver Island. With support from NETL, the drill ship Joides Resolution will depart from Astoria Oregon on Sept 21 or 22 and conclude in Victoria, British Columbia on October 29, 2005. The focus of this gas hydrates dedicated cruise is to further constrain models for the formation of marine gas hydrate in subduction zone accretionary prisms, such as are present in the offshore area west of Vancouver Island, Canada. A better understanding of the deep origin of methane, its upward transport and incorporation into hydrate deposits, and its subsequent release at the seafloor will be a major objectives. NETL is supporting this effort by enabling the deployment of the HYACINTH pressure coring systems and associated core logging equipment capable of acquiring hydrate samples at *in-situ* pressure conditions for subsequent examination aboard the ship and in later laboratory studies. X-ray linear scanning of these cores and post expedition x-ray computed tomography (CT) scans of hydrate samples will also be conducted. (further information on Expedition 311 including maps showing its offshore location, etc. can be obtained at http://iodp.tamu.edu/publications/SP/311SP/311SP.html/.



## 2005 Energy Policy Act Authorizes Methane Hydrate R&D Through 2010

On August 8, 2005, President George W. Bush signed into law The Domenici-Barton Energy Policy Act of 2005. Section 968 of the new law extends the Methane Hydrate R&D Act of 2000 through 2010, and authorizes $155 million in R&D spending over the next five years.

The Secretary of Energy, along with the Secretary of Commerce, the Secretary of Defense, the Secretary of the Interior, and the Director of the National Science Foundation will designate individuals to coordinate the national R&D program, through partnerships with industry, universities, research institutions, and other government agencies.

The Act directs the program to; 1) identify methane hydrate resources through remote sensing; 2) acquire and reprocess seismic data for characterizing methane hydrate accumulations; 3) develop efficient and environmentally sound technologies for developing methane hydrate resources; 4) promote education in methane hydrate research by means of fellowships or other graduate level incentives; 5) conduct research to evaluate and mitigate environmental impacts of hydrate gas emissions; 6) develop technologies to reduce risks associated with drilling through hydrate; and 7) conduct exploratory drilling and production testing of hydrate accumulations in permafrost and non-permafrost environments.

As in the past, the program will be carried out with the help of a federal advisory panel, including representatives from industry, universities, and other research institutions. Funding under the Methane Hydrate Research and Development Program will be made available through a competitive process using external scientific peer review.

For more information, scroll down to "Section 968 - Methane Hydrate Research" of the Energy Policy Act of 2005, which is available online at: http://energycommerce.house.gov/108/0205_Energy/conference/EnergyConf_report.pdf

## New Projects Selected for Cost-Shared Funding

NETL has completed its review of proposals received under its FY2005 Methane Hydrates solicitation. Given the available funding ($1.3 million), the program sought relatively modest projects (e.g., those utilizing existing data as opposed to new field programs) to address specific gaps in the program portfolio and to produce foundational studies that would support subsequent major field efforts. Proposals were reviewed for technical merit by a 3-person NETL review team, as well as six external ex-officio reviewers organized through the interagency Technical Coordination Team. The DOE then selected five projects from among 18 applicants.

***Stanford University: "Seismic-scale Rock Physics of Methane Hydrate"***—Stanford Univeristy scientists, under the direction of Dr. Amos Nur, will extend existing rock-physics models to shallow, unconsolidated hydrate-bearing sediments through iterative computer simulation of seismic response and analysis of existing seismic datasets. The results are expected to inform all future seismic-based investigations of hydrate deposits.

***Texas Engineering Experiment Station (TEEX): "Geomechanical Performance of Hydrate-Bearing Sediments In Offshore Environments"—***TEEX scientists, led by Dr. Steve Holditch, will conduct laboratory experiments and couple two existing state-of-the-art computer simulators (one addressing hydrate thermodynamics and another dealing with mechanical stability) to provide critical basic data on the stability of hydrate-bearing sediment, both in the vicinity of conventional oil and gas production operations, as well as during future hydrate production.

***Woods Hole Oceanographic Institute (WHOI): "Gas Hydrate Instability in the Southeastern Bering Sea"—***The WHOI, led by Dr. Lloyd Keigwin, will investigate the links between methane hydrates and global climate through detailed geochemical study of pre-existing full sediment cores from the Bering Sea, offshore Alaska. The study will study geochemical markers in the sediment that will provide information on the timing and magnitude of past events of rapid methane incursion into the sea-water.

***Battelle Memorial Institute: "Comparative Assessment of Advanced Gas Hydrate Production Methods"—***Dr. Pete McGail will lead a partnership between Battelle and the University of Alaska-Fairbanks to assess the potential commercial viability of various methane hydrate production methods that utilize $CO_2$ injection. If successful, the methodwill provide a compelling synergy of; 1) mechanical support to thereservoir (by producing CO2 hydrate to replace the dissociated methanehydrate); 2) incremental support to the ongoing hydrate dissociationreaction; and 3) options to utilize and sequester a portion of the CO2 thatis expected to be produced in association with North Slope gas.

***University of Texas – Austin: "Combining Multi-component Seismic Attributes, New Rock-Physics Models, and In Situ Data to Estimate Gas-Hydrate Concentrations in Deep-Water, Near-Seafloor Strata of the Gulf of Mexico"—***UT-Austin, under the direction of Dr. Bob Hardage, will utilize a unique, high-value, state-of-the art ocean bottom seismic dataset in an area with significant potential for hydrate occurrence in the Green Canyon area of the deepwater Gulf of Mexico to assess the relative diagnostic capabilities and cost-benefit of OBS seismic as a means of characterizing marine hydrate occurrences.

## Mallik Volume Now Available

The results of the Mallik 2002 Gas Hydrate Production Research Well Program are now available for ordering through the Geological Survey of Canada. The comprehensive volume, edited by S. R. Dallimore and T. S. Collett with assistance from co-editors A.E. Taylor, T. Uchida, M. Weber, A. Chandra, T.H. Mroz, E.M. Caddel, and T. Inoue, includes 62 papers, representing 172 contributing authors. Abstracts of all 62 papers are published in printed form, with full text versions on an accompanying CD-ROM, and an interactive scientific database on an accompanying DVD. The volume is published as Geological Survey of Canada Bulletin 585 "Scientific Results from the Mallik 2002 Gas Hydrate Production Research Well Program, Mackenzie Delta, Northwest Territories, Canada." It is available for purchase from the Geological Survey of Canada Bookstores, at http://gsc.nrcan.gc.ca/gashydrates/mallik2002/bulletin585_e.php/.

The Geological Survey of Canada Bookstore (Ottawa) can be reached toll-free at (888) 252-4301, or by email at gscbookstore@nrcan.gc.ca.

## Alaska Gas Hydrate Planning Workshop

On August 17-18, 2005, the Alaska Department of Natural Resources and the U.S. Geological Survey hosted a workshop in Anchorage, Alaska with the primary goal of developing an improved understanding of the energy resource potential of gas hydrates in northern Alaska and identifying the various scenarios for achieving that goal. The workshop was attended by more than 50 participants, representing industry, government, and academic stakeholders in Alaska. Electronic copies of the proceedings and associated presentation material can found on the following web site: http://www.dggs.dnr.state.ak.us/AlaskaGasHydrates.htm/.

# Engineering Mentor Gains New Perspective on Hydrates

**DR. E. DENDY SLOAN**

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For the past 30 years Dendy Sloan's laboratory at the Colorado School of Mines (CSM) has solved pipeline flow assurance problems for industry, investigating the basic physical, chemical and engineering aspects of hydrates formed inside pipelines. More recently, Dendy has applied this research to the study of hydrates outside pipelines, especially for hydrated methane energy and the influence of hydrates on seafloor stability and climate change. During the last 15 years, the emphasis has been on methane hydrates as a potential source of natural gas. But Dr. Sloan believes that perhaps the most important product of his CSM lab has been something else altogether: a steady stream of competent engineers.

*"Undoubtedly, my most important contribution to the field is the small part I played in the education of colleagues who obtained graduate degrees in my laboratory – outstanding people like USGS' Tim Collett, Shell's Ajay Mehta, David Peters, and Marc Jager, Chevron's Patrick Mathews, Siva Subramanian, and Ramesh Kini, BP's Adam Ballard, Taras Makogon, and Phaneendra Bollavaram, and SINTEF's Roar Larsen to name just a few,"* says Dendy. *"These folks represent a good portion of the intellectual future of hydrate research, and our current group of hydrate researchers continually revitalizes my hydrate perspective."*

This view is particularly interesting because Dendy Sloan began his career not in academia but in industry, as a chemical engineer building and starting up a series of DuPont chemical plants along the East Coast before he returned to graduate and postdoctoral education at Clemson and Rice Universities. *"At Rice in 1975, Professor Kobayashi and I measured two-phase hydrate data to answer a seemingly urgent question*


*The CSM hydrate research group. Dr. Sloan is the one with the bow tie.*

*for an Alaskan natural gas pipeline project – how should the gas be dried to prevent hydrate formation during transport to the lower 48 states?"* Although the pipeline has yet to be built, the project served to establish Dendy's fascination with the behavior of hydrates.

Since then, Dr. Sloan has remained keenly interested in gaining a molecular perspective on hydrates through the application of new tools such as Raman spectroscopy, nuclear magnetic resonance spectroscopy and x-ray diffraction as supplements to the normal macroscopic measurements of pressure, temperature, and composition. *"In the past, most engineering applications measured every phase except the hydrate phase to determine hydrate formation and dissociation conditions,"* Sloan explains. *"With spectroscopic methods, accuracy is greatly increased."* This new experimental capability has led to discoveries – the kinetic inhibitor concepts, the phase equilibria of structure H hydrate, a new methane hydrate phase diagram, and the discovery that two structure I hydrate formers (methane and ethane) would form structure II as a mixture.

Dendy is also excited to be participating in a number of state-of-the-art summaries related to methane hydrate research, including two books, the first of which is currently being written in its third edition. *"The first of the tri-annual International Hydrate Conferences was held in 1993 and to see it grow to its fifth conference in 2005 is very rewarding,"* adds Sloan. He also chairs the international CODATA effort to make an electronic hydrate database freely available to the public by 2008.

Asked for his thoughts on the future of methane hydrate research, Dr. Sloan responds that he is in general agreement with the findings of the National Research Council report in 2004. *"One could imagine a roadmap for hydrate exploitation that involves four steps: 1) proof of concept of extracting gas from a high concentration permafrost hydrate reservoir – for example the 2002 Mallik Well, 2) proof of long-term hydrate production from a high concentration permafrost hydrate reservoir, 3) demonstration of the transfer of permafrost hydrate gas recovery technology to a high concentration ocean hydrate reservoir, and finally, 4) transfer of gas recovery technology to low hydrate concentrations in the ocean."*

Sloan points out that for hydrate exploitation, there has yet to be published an encouraging economic study for gas recovery from hydrates in reservoirs where the hydrates do not overlie conventional gas accumulations. *"A second problem is that an engineering breakthrough will be required for recovery of gas from low concentration ocean hydrates. We will need to be innovative to get beyond the three standard methods initially stated by Professor Y. Makogon: depressurization, thermal stimulation, and inhibitor injection."*

When not focused on the structure of hydrates, Dendy enjoys being with Marjorie, his attorney-wife of 40 years, long-distance bicycle touring, and trying to master music for stringed instruments. His most recent challenge in this regard has been Bach's Suites for Unaccompanied Cello. Dendy also enjoys philosophy, both in and out of the laboratory, as evidenced by his continued enthusiasm for methane hydrate research where, in his words … *"It is a existential pleasure to discover physical portions of the world which were previously unknown."*