the ENERGY lab

# Fire in the Ice

Vol. 11, Issue 1 Methane Hydrate Newsletter

NETL

## CONTENTS



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U.S. DEPARTMENT OF ENERGY

# Iġnik Sikumi #1, Gas Hydrate Test Well, Successfully Installed on the Alaska North Slope

*By David Schoderbek (ConocoPhillips) and Ray Boswell (National Energy Technology Laboratory)*

On April 5, 2011, Nordic-Calista Drilling Rig #3 rig rolled onto a temporary ice pad constructed within the Prudhoe Bay Unit (PBU), Alaska North Slope, and commenced operations on the "Iġnik Sikumi" (Iñupiaq for "fire in the ice") gas hydrate field trial well (Figure 1). The health, safety, and environmental incident-free field program was operated by ConocoPhillips, Alaska, Inc., acting with the permission of the Prudhoe Bay Unit Working Interest Owners, as part of an ongoing cooperative research agreement with the U.S. Department of Energy. The rig was released from the site on April 28 after conducting a comprehensive downhole data acquisition and site characterization program, installing a complex and fully-instrumented wellbore completion that will be available for additional field experiments to be initiated as early as winter 2011-2012.

### Background

The Iġnik Sikumi #1 well is designed to enable a short-duration field trial of a potential gas hydrate production technology (see Farrell *et al.*, FITI March 2010) that utilizes the injection of $CO_2$ into gas hydrate-bearing sandstone reservoirs, resulting in a chemical exchange reaction

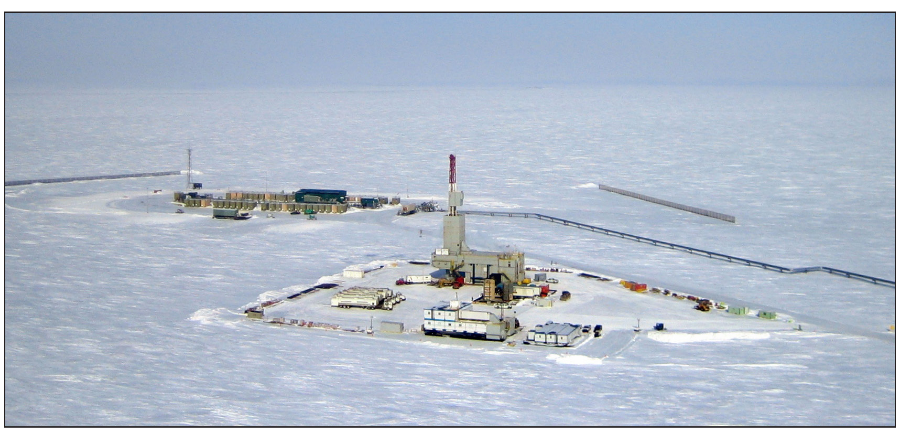

*Figure 1: Nordic #3 Drill Rig at site of Iġnik Sikumi #1 well, Prudhoe Bay Unit, Alaska, in April 2011. The PBU L-pad is in the background (courtesy ConocoPhillips).*

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that releases methane gas ($CH_4$) while simultaneously sequestering $CO_2$ in a solid hydrate structure as $CO_2$-hydrate. The field trial is a major milestone in a research program based on experimental and numerical modeling studies conducted by ConocoPhillips in partnership with the University of Bergen to demonstrate the potential technical feasibility of the exchange process within porous and permeable sandstone reservoirs under the pressure and temperature conditions that are typical of Alaska North Slope gas hydrates (see ConocoPhillips, FITI, Fall 2008). The location for the test well, near the Prudhoe Bay Unit L-pad, was selected by the project team following a full review of potential test sites in Alaska because of its low geologic risk and the inferred presence of multiple potential test horizons (for a related discussion of potential sites of gas hydrate field tests in Alaska, see Collett and Boswell, FITI, Summer 2009).

### Operations

A 500 ft by 500 ft temporary ice pad was constructed adjacent to the permanent road to the PBU L-pad in March, 2011. Nordic Rig #3, as well as a rig camp for 70 workers, arrived in early April, and the well was spud on April 9, 2011. The "surface" hole was drilled using water-based drilling fluid and Logging-While-Drilling (LWD) measurements to a depth of 1,482 ft, where 10¾" surface casing was run, cemented, and pressure-tested (Figure 2). LWD operations continued using chilled oil-based drilling fluid to minimize thermal disturbance of the permafrost and hydrate-bearing formations. The well reached a total depth of 2,597 ft on April 17. A full suite of wireline well logs were then obtained (including gamma-ray, resistivity, high-resolution density, neutron porosity, oil-based drilling fluid imaging, combinable magnetic resonance, sonic scanner, and borehole resistivity scanner) followed by a series of short-duration wireline pressure tests utilizing Schlumberger's Express Pressure Tool (XPT) and Modular Formation Dynamics Tester (MDT).

Upon completion of the data acquisition program, a completion was installed consisting of a fully-instrumented tapered casing string that included downhole temperature and pressure gauges and a continuous Distributed Temperature Sensor (DTS) cable (Figure 2). All equipment was fully functional and monitored throughout cementing operations, which were completed April 25th. The upper completion was then installed, which included chemical injection mandrel and gas-lift mandrel. The well was temporarily suspended, with the rig moving off location on April 28th.

### Results

Wireline data indicate that four gas-hydrate-bearing sand horizons were encountered at Iġnik Sikumi #1, as expected. The primary test target, the Sagavanirktok "Upper "C" sandstone (2214 to 2274 ft below the rig floor) contains 44 feet of clean, high-porosity sandstone with very high gas hydrate saturations within the optimal pressure-temperature conditions to conduct the planned field trial (Figure 3). The secondary target, the overlying "D" sandstone (2060-2114 ft), contains 49 feet of slightly siltier

# Iġnik Sikumi #1

***Well Schematic***

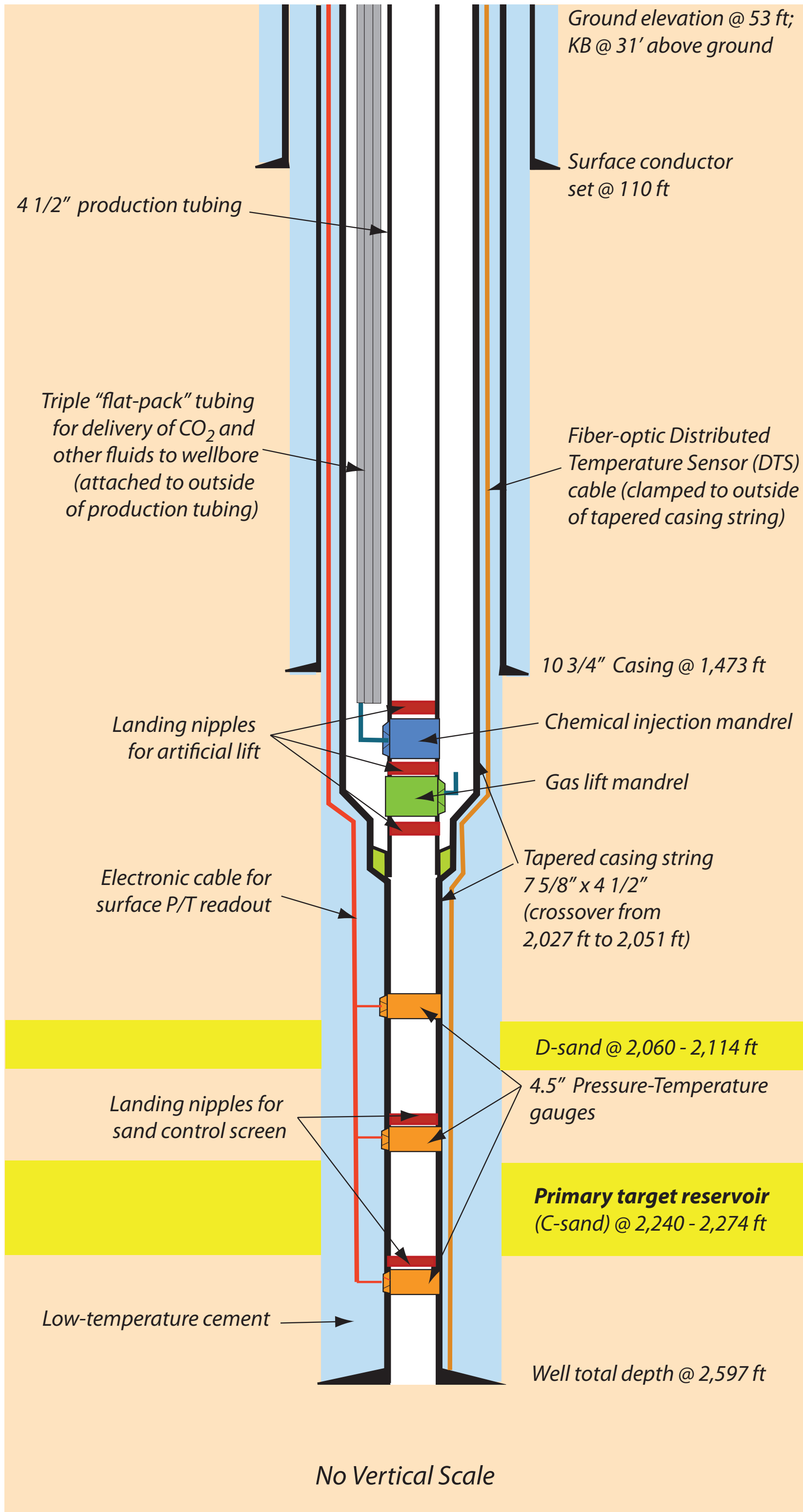


*Figure 2: Schematic of the well completion for the Iġnik Sikumi #1 well.*

sandstone with slightly lower gas-hydrate saturations. The shallower "E" sandstone (1920-1954 ft) contains 31 feet of siltier sandstone with intermediate gas-hydrate saturations. The deeper "Lower C" sandstone (2278-2362 ft) contains an additional 36 feet of gas-hydrate bearing sandstone interbedded with siltstone and underlain by water-saturated sandstone (Figure 4). The XPT tool successfully obtained data at 16 levels to provide insight into the ambient reservoir pressure and potential injectivity of various stratigraphic units, while the MDT tool was used primarily to conduct "mini-frac" tests, designed to measure breakdown pressures, the pressure at which fluids may be injected before the formation will fail via extensional fracturing. All these datasets are currently under review.

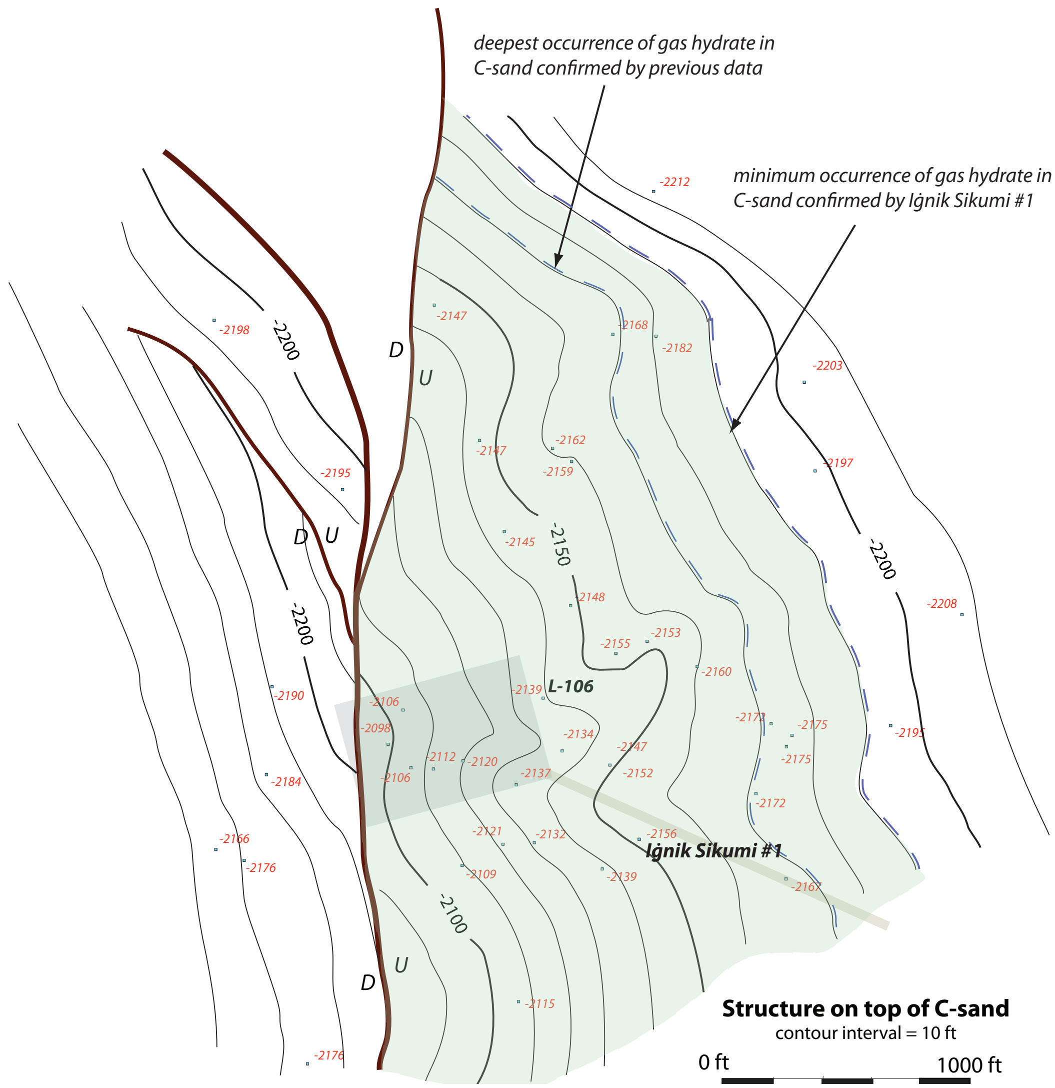


*Figure 3: Structure map on the top of the main gas hydrate-bearing interval within the target C-sand.*

Iġnik Sikumi #1 Log Data

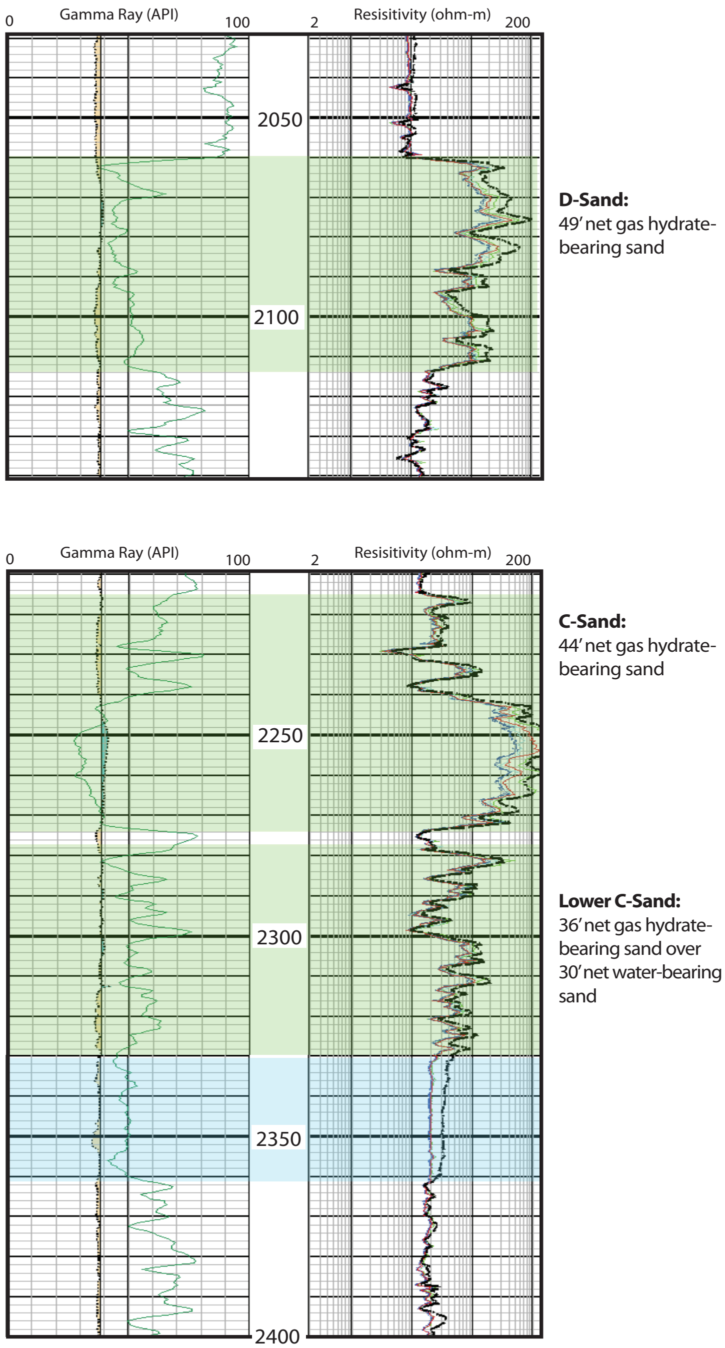


*Figure 4: Selected wireline well log data (gamma ray and resistivity) showing the occurrence of gas hydrate (green shading) within three sand horizons in the Iġnik Sikumi #1 well.*

## Next Steps

In the coming months, field trial participants will review the geologic, petrophysical, and engineering data collected during the field program to determine the optimal parameters for future field testing. The readings from the down-hole DTS will be monitored to assess conditions within the well, including the rate at which temperatures equilibrate from the disturbance related to the well installation back to normal background gradients.

Assuming all participants concur that the site remains suitable for testing, current plans are to rebuild a smaller ice pad around the wellhead early in the next winter drilling season. The well will then be re-entered, the well condition assessed, and the casing perforated over the chosen test interval. The program will begin with $CO_2$ injection and shut-in for exchange, followed by stepwise depressurization and flowback. Contingencies for managing free water in the formation or for dealing with potential low injectivity will be evaluated and implemented as needed. Once the exchange trial objectives of the testing program are met, the team plans to utilize the wellbore for continued production testing, including extended formation depressurization, for a period that may extend to the end of the winter 2011-2012 operating season.

*U.S. DOE Deputy Assistant Secretary for Oil and Gas, Christopher Smith, David Schoderbek (ConocoPhillips), and Ray Boswell (U.S. DOE-NETL) at the Iġnik Sikumi well site.*

# 2ND ULLEUNG BASIN GAS HYDRATE EXPEDITION (UBGH2): FINDINGS AND IMPLICATIONS

*By Sung-Rock Lee, Gas Hydrate R/D Organization (GHDO) & UBGH2 Science Party (Chief scientist: B.J. Ryu, KIGAM)*

UBGH2 was performed from early July 2010 to September 2010 to explore gas hydrate in the Ulleung Basin, East Sea, offshore Korea, onboard the D/V *Fugro Synergy* (Figure 1). The primary objectives of the UBGH2 campaign were: (1) to understand geological occurrences and to collect geophysical data for understanding the distribution of hydrate-containing structures as required for the hydrate gas resource assessment and (2) to find promising candidate areas suitable for a future offshore production test, especially targeting sand bodies that contain hydrate to confirm the presence of gas-hydrate bearing sediments and/or gas hydrate in the Ulleung Basin.

The drilling sites were selected through discussions held during the International Advisory Committee Meeting (USA, Canada, UK and Korean scientists). Based on geological and geophysical data, including 2-D and 3-D seismic survey, from 25 prospect sites, 10 were selected and ranked by priority. These 10 sites were then divided into four groups according to seismic characteristics that indicated gas hydrate presence. The proposed sites cover much of the Ulleung Basin, East Sea. Group I included regions with dipping strata and intersecting bottom-simulating reflectors (BSR). Group II included vertical acoustic blanking zone and column structures. Group III included horizontal acoustic blanking zone that is connected by column structures below gas hydrate stability zone in the middle of the Ulleung Basin. Group IV included an area of 3-D seismic imaging conducted in 2008 and also included previous drilling sites where sand bodies were identified during the 2007 expedition. The wells were drilled to depths approximately 50 m below the BSR. Thus, the expected drilling depths ranged from 230 m to 360 m below seafloor. The water depths at the proposed sites ranged from 910 m to 2160 m.

### PARTICIPATING UBGH2 ORGANIZATIONS

- •Korea Gas Hydrate R&D Organization (GHDO)
- •Korea National Oil Cooperation (KNOC)
- •Korea Institute of Geoscience & Mineral Resources (KIGAM)
- •Korea Gas Cooperation (KOGAS)
- •Korea Ocean Research & Development Institute (KORDI)
- •Hanyang University (HYU)
- •Korea Advanced Institute of Science & Technology (KAIST)
- •U.S. Geological Survey (USGS)
- •Geological Survey of Canada (GSC)
- •Oregon State University (OSU)
- • Fugro
- •Geotek Ltd.
- •Schlumberger
- •Science Technology Network (STN)

### Shipboard Activities

UBGH2 consisted of two phases. Phase One included Logging-While-Drilling (LWD) operations at 13 sites and lasted about one month. Phase Two included coring and Wireline Logging (WL) operations at nine sites. In addition to logging and coring operations, seafloor observation and sampling using ROVs were conducted during both phases.

*Figure 1: The Fugro Synergy. Photo courtesy of Bergen Yards.*

On-board analyses included sedimentology, geochemistry, physical property, and pressure core analysis. Sedimentology analyses included conventional core image scanning, observations of split cores, smear slides, and grain size analyses. Geochemistry included pore water and gas chemistry analysis and sub-sampling for post-cruise study of sediment chemistry and microbiology. Physical property measurement included scanning of geophysical properties such as magnetic susceptibility, *P*-wave velocity and gamma ray density and measurement of moisture and density analyses, contact *P*-wave velocity and resistivity, thermal conductivity, and shear strength measurement (Figure 2). Pressure core analyses included X-ray scanning, non-destructive measurement of *P*-wave velocity and gamma ray density, slow depressurization for hydrate quantification, and sub-sampling for post-cruise analyses. Especially in pressure core operations, the first attempt to perform on-board production test with vertical effective stress applied was successfully made, generating interesting measurements and results. The effective stress cell, KIGAM's GHOBS (Gas Hydrate Ocean Bottom Simulator) is compatible with Geotek's PCAT system and has capability of *P*- & *S*- wave and resistivity measurements as well as vertical displacement and gas and water production rate while simulating consolidation and production operations.

**Preliminary Findings**

The shipboard analysis results collectively indicate that recovered gas hydrates mainly occur either as "pore-filling" bounded by discrete turbidite


*Figure 2: KIGAM scientists at work: J.Y. Lee prepares for an on-board pressure core production test (upper) while her crewmates perform physical property measurements on conventional cores (lower).*

sand or ash layers, or as "fracture-filling" veins and nodules in pelagic/hemipelagic mud. In addition, minor but significant variation was also observed in some pelagic mud where gas hydrates occur as "pore-filling" without considerable changes in sand contents between bounding and surrounding layers. Hydrate veins and 10 to 30 cm-thick hydrate layers were found and could be visually observed as shown in Figure 3. Sometimes, pore-filling type hydrate in sandy layers could also readily be observed with IR images as shown in Figure 3. In a few sites, relatively thick hydrate-bearing sandy layers interbedded with muddy layers were found (Figure 4), suggesting the possibility of test production.

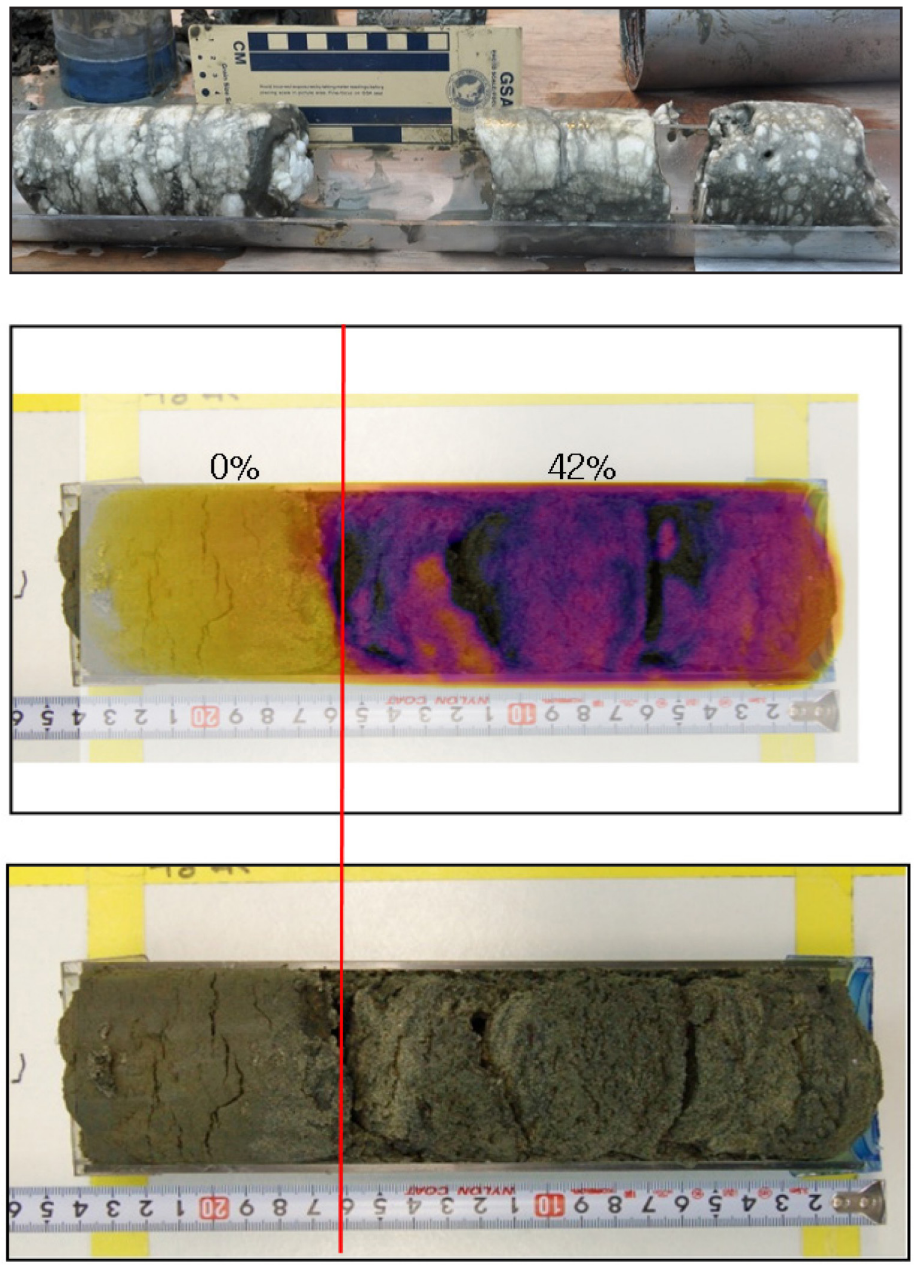


*Figure 3: Hydrate samples retrieved during UBGH2: 30 cm thick bulk hydrate (upper), pore-filling type hydrate in sandy layer observed by IR images and hydrate saturation calculated from pore water analysis (lower).*

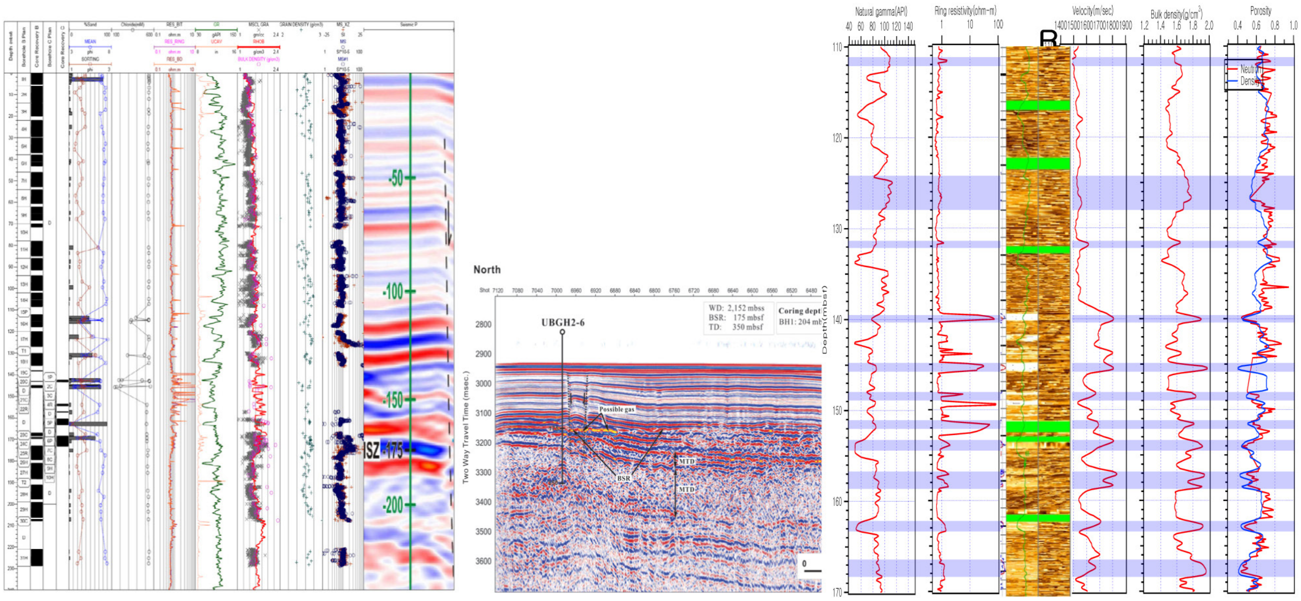


*Figure 4: LWD, seismic and geochemical variation profiles of UBGH2-6 site showing turbidite sand containing gas hydrate alternating with mud-rich layers containing gas hydrate.*

## ACKNOWLEDGMENTS

Special thanks should be expressed to the Ministry of Knowledge Economy (MKE) and all members of the Science Party including: KIGAM, KNOC (contractor of UBGH2 operation), KOGAS, DOE/NETL, USGS, OSU, GSC, KAIST, HYU, KORDI, STN, Geotek, Schlumberger and Fugro.

### Ongoing and Future Activities

Samples for post-cruise analysis were determined before the start of the expedition, and the samples are now being analyzed. A Gas Hydrate Drilling Sample, Data and Obligation Policy has also been established for organized distribution of data and samples obtained from UBGH2. A UBGH2 Post-cruise Meeting was held at KIGAM in February 2011, and the initial report will be completed by March 2012. For additional information, please contact Sung-Rock Lee at srlee@kigam.re.kr.

*UBGH2 science party on the heliport at the end of the cruise.*

# Sedimentological Control on Saturation Distribution in Arctic Gas-Hydrate-Bearing Sands

*By Javad Behseresht and Steven Bryant (University of Texas at Austin)*

We describe a mechanistic model to predict the distribution of hydrate saturation in sands below permafrost. The essential features of the model are (i) the descent of the base of the gas hydrate stability zone (BGHSZ) through an accumulation of gas in the sand; (ii) the volume change associated with hydrate formation from gas and water phases; and (iii) the variation of grain size distribution with depth. We test the model on field data from Mt. Elbert gas hydrate stratigraphic test well, drilled in the Milne Point area of the Alaskan North Slope. The test well indicates two zones of large gas hydrate saturation in the stratigraphically highest portions of two sand units. Small hydrate saturations occur in the lower portions of each unit, even though those portions are sand-rich. The model explains the physical origin of these features.

## Introduction

Grain size varies with depth in most depositional environments. When gas accumulates in a sediment, these variations play an important role on the gas/water saturation profile. Figure 1a shows schematically a stack of four distinct sediment layers with different grain size distributions. Each layer thus has a different characteristic capillary pressure curve, as shown in Figure 1b. The top layer (layer 1) has the smallest grains, and the corresponding capillary pressure curve shows a much larger entry pressure than other layers. If gas enters this stack of sediment from the bottom of layer 4 (Figure 1a) and begins to accumulate, the capillary pressure increases with gas column height above the entry point as shown in Figure 1c. The capillary pressure at any height combined with the corresponding drainage curve (Fig 1b) yields the gas/water saturation profile shown in Figure 1d. The fine-grained layer 1 acts as a seal for the gas accumulation in Figure 1d. Note that BGHSZ is above the gas column and thus no hydrate is present in Figure 1d. Once BGHSZ has moved all the way down the gas column, a hydrate saturation profile such as that shown in Figure 1e is observed in wells such as the Mt. Elbert test well. Our model explains how this "sandwich" profile of large and small hydrate saturations arises.

## Method

The stoichiometry of the $CH_4$/$H_2O$/hydrate reaction and the densities of the gas, brine and hydrate phases can be used to calculate the hydrate saturation profile, given the initial gas/water saturation profile inside the host sediment. For typical sub-permafrost conditions, hydrate occupies less volume than the gas and water phases. Thus both gas and water phases may enter the sediment to fill the void caused by hydrate formation. The ratio of these void-filling volumes is the free parameter in the model used here. We also assume that hydrate forms over long time intervals during which any increases in salinity and temperature are quickly dissipated, so

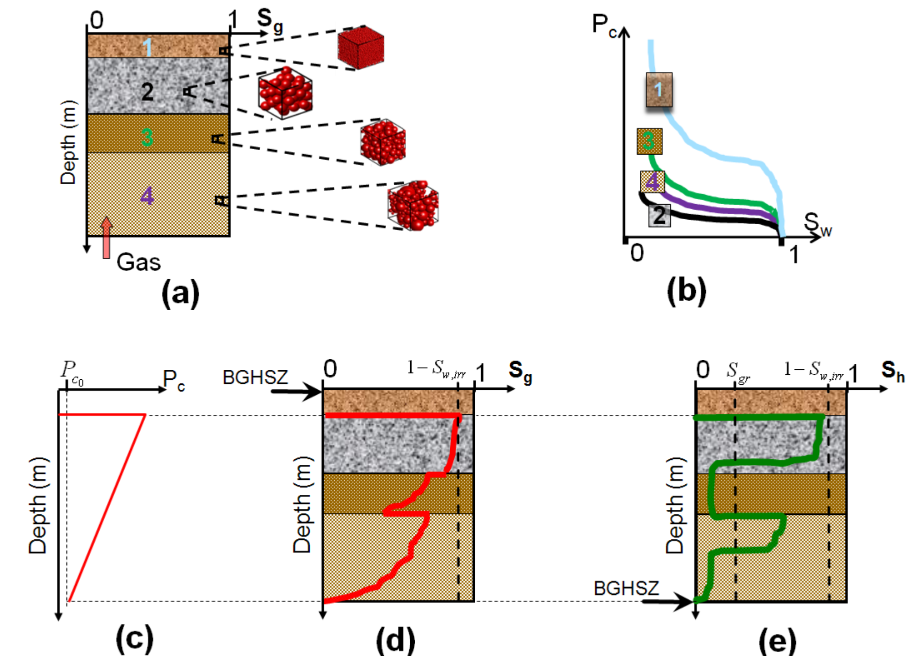


*Figure 1: (a) Sediment layers with different grain size distributions. The characteristic capillary pressure for each layer is shown in (b). Gas enters the bottom layer and accumulates below the fine-grained layer at top of sediment package. (c) Capillary pressure profile within the gas column, combined with the characteristic curves of (b), determines the gas saturation profile (d) through the sediments. Note that gas accumulation has occurred while BGHSZ is shallower than the gas column and thus no hydrate is being formed so far. (e) As BGHSZ descends along the sediment column, a hydrate saturation profile (e) is established which can be very different from the initial gas saturation profile.*

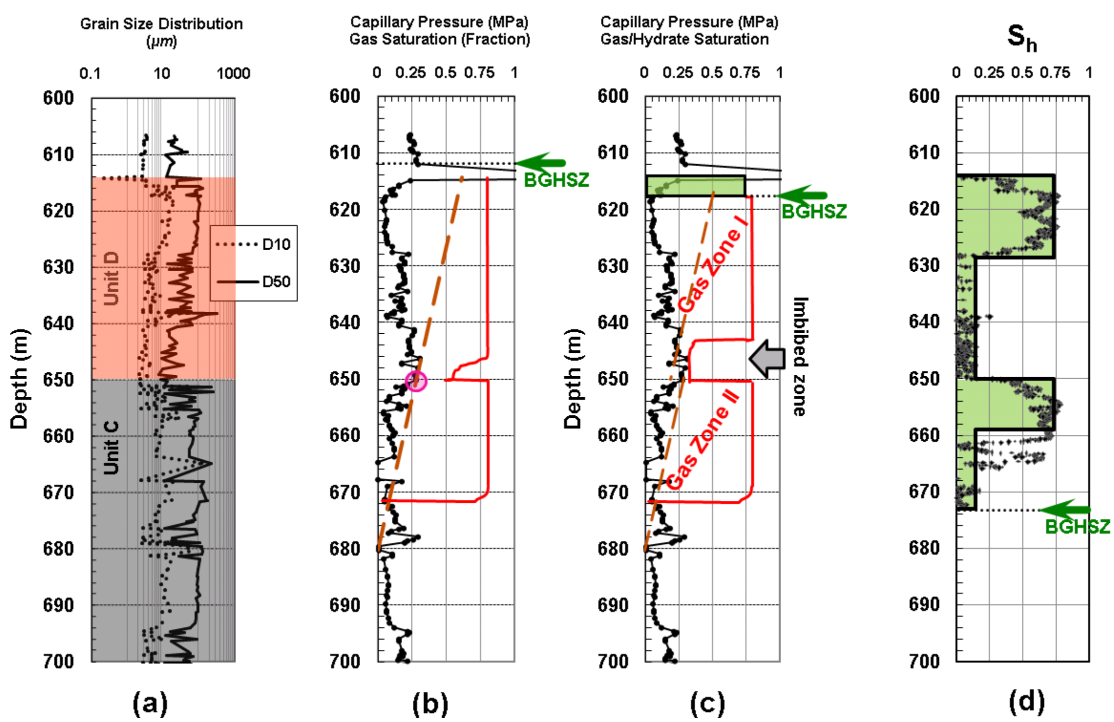


*Figure 2: (a) The 10th (D10) and 50th (D50) percentile of grain size versus depth in Mt. Elbert well. (b) Capillary entry pressure estimated from (a) versus depth (line with symbols) along with estimated initial gas saturation (red solid line) before the formation of hydrate, when BGHSZ was above the zone in which hydrate is currently observed. The gas saturation profile changes from its initial value as BGHSZ moves down, and gas moves within the accumulation to fill the void caused by hydrate formation. (c) Situation when BGHSZ has moved 3.5 meters downward. To compensate for the methane consumed to form hydrate, gas from the lower portion of Unit D moved up and water imbibed from below to create gas zone 1. Gas zones I and II are no longer in communication due to the entry pressure barrier between them at 650 m. (d) Situation after BGHSZ has moved all the way through the gas column. Predicted final hydrate saturation (green area) forms a sandwich of large and small values. The log derived hydrate saturations are shown as dots.*

that hydrate formation is not hindered. Thus in any control volume within the sediment, hydrate continues to form until one of the components ($H_2O$ or $CH_4$) is exhausted.

As illustrated in Figure 1, grain size variation plays an important role in the way gas saturation is established within the host sediments. We find that this variation also determines the hydrate saturation profile. To account for the effect of grain size variation, we estimate capillary entry pressure from grain size distribution (Figure 2a) at each depth using Breyer's method for hydraulic conductivity evaluation (1975).

**Results**

Figure 2b shows the estimated capillary entry pressure profile in the Mt. Elbert well (black line with symbols) along with estimated gas saturation prior to BGHSZ descent (solid red line) and the corresponding gas phase capillary pressure (dashed orange line). The fine-grained layer at 614 m depth acts as a top seal for the ~60 m gas column. The gas is assumed to have entered the layers at a depth of 672 m and is no longer in contact with the presumed source of gas. As BGHSZ descends, hydrate forms, Figure 2c. Gas moves upward to help fill the void caused by hydrate formation. Consequently the gas-water contact at 672 m moves slightly upward, and the gas capillary pressure slightly decreases. This causes the capillary pressure at 650 m to drop below the entry pressure for the sediment at that depth (magenta circle in Figure 2b). Crucially, this disconnects the gas accumulation into an upper portion in Unit D (between 614 m and 650 m) and a lower portion in Unit C (650 m to 672 m). Figure 2c shows an intermediate step when BGHSZ is at a depth of about 618 m. Note that gas moving to fill the void due to hydrate formation now rises from the bottom of the upper portion of the accumulation, establishing a residual gas saturation between 644 m and 650 m. When the BGHSZ has moved all the way through the gas accumulation, the hydrate saturation profile shows two regions of large saturation and two regions of small saturation, Figure 2d. The small saturations correspond to the conversion of residual gas saturation to hydrate.

The model predictions match the field data (log-derived hydrate saturation shown as symbols in Figure 2d) reasonably well. Notably, the model explains why in unit C the major methane hydrate accumulation is at the top lower-quality sand rather than the bottom better-quality deposit, and how a nearly uniform initial gas saturation profile leads to a sandwich-like hydrate saturation profile.


## ACKNOWLEDGMENTS

Enlightening discussions with Bill Winters, Ray Boswell, Kelly Rose and Carlos Santamarina helped bring this work to fruition. The grain size measurements in Figure 2 are courtesy of K. Rose and W. Winters. Funding for this research comes from NETL Methane Hydrates Program (DE-FC26-06NT43067).

# A New Global Gas Hydrate Drilling Map Based on Reservoir Type

*By C. Ruppel[1], T. Collett[1], R. Boswell[2], T. Lorenson[1], B. Buczkowski[1], and W. Waite[1]*

*[1] U.S. Geological Survey*
*[2] DOE National Energy Technology Laboratory*

Several types of maps depicting global gas hydrate occurrences have been formulated, since large amounts of field data began to be acquired several decades ago. Here, we propose a new type of map that highlights the resource potential of gas hydrates in locations that have already been sampled by deep drilling.

Historically, global maps related to gas hydrates have fallen into a few categories. The first type portrays the locations where pressure-temperature conditions in the sedimentary section are inferred to be appropriate for forming gas hydrates in the deep ocean and in permafrost regions. Such maps can be based on models that range from straightforward to relatively sophisticated, depending on the degree to which they incorporate global datasets on sediment thickness, organic carbon content, thermal regimes, and similar factors (e.g., Buffett and Archer, 2004; Wood and Jung, 2008). Scaled down to individual regions and with local detail included, such maps can provide important guidance for field surveys. Typically these maps emphasize prospective occurrences though, without regard to sediment properties that in part control gas hydrate saturations.

Another type of map and associated database records where gas hydrate has been visually observed upon the recovery of sediments, sometimes without distinction between shallow gas hydrates accessible by piston cores and deeper gas hydrates studied during drilling programs (e.g., Booth *et al.*, 1996; Kvenvolden and Lorenson, 2000). Shallow and deeper-seated gas hydrates are not equally important in a consideration of climate, hazard, and energy resource issues, and their inclusion on the same map can be misleading. Shallow gas hydrates (<50 m) are more susceptible to changes in the ocean-atmosphere system and in some cases may represent a near-seafloor drilling hazard; however, they are not considered targets for natural gas production for a variety of technical and safety reasons. Deeper-seated gas hydrates that occur as high saturation deposits could eventually be good targets for production, and the gas evolved from these gas hydrates during drilling could in some cases become a hazard without appropriate controls. Such deep-seated gas hydrates are not very important for climate issues, since they could only emit methane to the ocean-atmosphere system if warming were particularly profound or long-lived.

Other drawbacks of maps focusing on gas hydrates that have been visually observed in recovered cores are biased towards (1) fractured fine-grained sediments, where massive gas hydrate occurring as fracture fill is more likely to survive core recovery; (2) locations where recovery conditions (e.g., colder water, shallower water column) are more conducive to gas hydrate preservation; and (3) well-surveyed areas or features of particular interest to researchers. In particular, some maps give the impression that the distribution and volume of gas hydrate are greater on US continental margins than on the margins of Africa, Asia, or India. Owing to heavy local and regional bias in sampling, caution must be exercised in drawing conclusions about the global distribution of gas hydrates on the basis of such maps.

Another kind of map portrays the distribution of bottom-simulating reflectors (BSRs) to indicate areas where marine gas hydrate might occur in the sedimentary section. The recovery of gas hydrate at locations where a BSR is lacking (e.g., Paull *et al.*, 1996 on the Blake Ridge; many locations in the Gulf of Mexico) underscores the limited niche for BSR maps. The presence of a BSR usually indicates that some gas hydrate, most commonly at low saturation, occurs near the base of the stability zone; a missing BSR in a gas hydrate-prone area may have several interpretations, including low methane flux (Xu and Ruppel, 1999), a petroleum system that focuses gas migration and disrupts pervasive, diffuse flux (e.g., Gulf of Mexico; Shedd *et al.*, 2009), and local perturbations in temperature, salinity, and/or methane flux that modify or destroy BSRs.

Here we develop a new kind of map (Figure 1) that categorizes deep-seated (>50 m subseafloor or subsurface) gas hydrate occurrences based on the resource pyramid (Figure 2) of Boswell and Collett (2006). Sites on the map include recent drilling locations and a combination of non-duplicative information from the Booth *et al.* (1996) database and the Kvenvolden and Lorenson (2000) database, which underwent a major update by B. Buczkowski in Woods Hole in 2008.

The resource categorization depicted on the map in Figure 1 and summarized in Table 1 is based on agglomerated findings for all the wells drilled in an area by programs related to gas hydrate evaluation. The map highlights only the generalized, primary (and sometimes secondary) reservoir type for wells drilled to date.

• Circles on the map mark the locations of drilling programs for which (1) gas hydrate was visually observed in recovered cores and (2) there was strong evidence for gas hydrates in high-quality borehole logs (e.g., resistivity, acoustic, and gamma ray) and/or pressure cores.

• Ovals show gas hydrate occurrences confirmed by advanced borehole logs (e.g., Gulf of Mexico) or a combination of logging and pressure coring (e.g., Gumusut-Kapak, Nankai MITI 1999-2000, some NGHP sites, Mt. Elbert and Mallik). At these locations, the data supporting the occurrence of gas hydrates are so unequivocal that visual observation of gas hydrate in recovered cores would add little new information. Note that the map does not include numerous locations where well logs are consistent with the presence of gas hydrate, but no focused gas hydrates drilling or study has been undertaken.

• Triangles denote the locations of DSDP/ODP Legs 66, 67, 84, 112, 127,

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and 131, and 146. Gas hydrate was observed in cores recovered on these expeditions, which pre-dated the first dedicated gas hydrates drilling on ODP Leg 164 and the development of an advanced framework for analysis of logging data in terms of gas hydrate occurrences. The designations of host lithologies for gas hydrates at these older DSDP and ODP sites are not as reliable or complete as those for more modern, gas hydrate-focused drilling programs.

• Lake Baikal drilling, associated with a diamond on the map, has not been widely documented, but appears to have recovered gas hydrate without associated logging.

• Messoyakha is the only major drilling activity designated with a square symbol, indicating that gas hydrate is inferred, but never confirmed by modern logs or drilling. Messoyakha arguably does not meet the criteria for inclusion on the map, but is so widely discussed in the gas hydrates resource literature that it is considered here for the sake of completeness.

A map at the scale shown in Figure 1 cannot capture the full range of geologic complexity in an area, and observations on a well-by-well basis must be considered when categorizing reservoirs at local and regional scales. In addition, existing wells may not necessarily intersect the most representative lithologies, the full range of lithologies, or the lithologies that may eventually prove to be the best gas hydrate resource targets for a given basin. Missing from the categorization in Figure 1 is an explicit consideration of ash layers, which will usually not be targets for resource-related gas hydrates drilling, but which have been observed to be cemented by gas hydrate at some DSDP/ODP/IODP holes and in some locations sampled during national drilling programs.

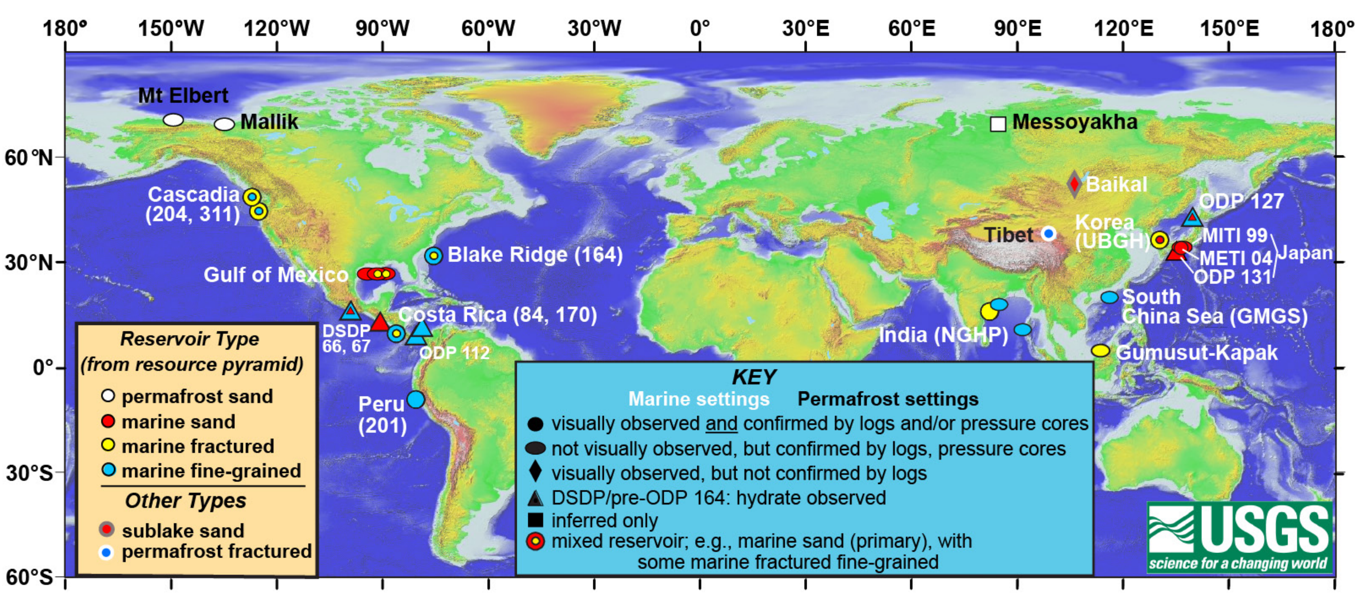


*Figure 1: Reservoir-based map of locations of gas hydrates found at subseafloor/subsurface depths greater than 50 m. Numbers in parentheses indicate DSDP/ODP/IODP expeditions.*

| Location (Drilling Program) | Generalized primary reservoir type | Generalized secondary reservoir type | Overview reference *(FITI = DOE NETL Fire in the Ice newsletter)* |
|---|---|---|---|
| ***Marine settings*** | | | |
| Blake Ridge (ODP Leg 164, Sites 994, 995, and 997) | Fine-grained | Fractured fine-grained | Paull *et al.*, *ODP Leg 164 Initial Reports*, 1996. |
| Costa Rica (ODP Leg 170) | Fine-grained | Fractured fine-grained | Kimura *et al.*, *ODP Leg 170 Initial Reports,* 1997. |
| Peru Margin (ODP Leg 201) | Fine-grained | | D'Hondt *et al.*, *ODP Leg 201 Initial Reports*, 2003. |
| Cascadia (ODP Leg 204; IODP Exp 311) | Fractured fine-grained | Fine-grained | Trehu *et al.*, *ODP Leg 204 Initial Reports*, 2003; Riedel *et al.*, *Geol. Soc. London Spec. Pub. 319*, 2009. |
| Korea (UBGH1 and 2) | Fractured fine-grained | Sands | Park *et al.*, *FITI*, Spring 2008; Ryu *et al.*, *Mar. Pet. Geol. 26*, 2009., Lee *et al.*, FITI (this volume) |
| India (NGHP1)<br>Krishna-Godavari Basin<br>*Mahanadi*<br>*Andaman* | <br>Fractured fg<br>Fine-grained<br>Fine-grained | | Collett *et al.*, *Indian National Gas Hydrate Program Expedition 01 initial reports,* DVD, 1828 pp., 2008. |
| Nankai<br>ODP Leg 131<br>*MITI 1999-2000*<br>METI 2004 | Sands | | Tsuji *et al.* and Fujii *et al. in*: Collett *et al.*, AAPG Memoir, 2009; Taira *et al.*, *ODP Leg 131 Initial Reports*, 1991; Tsuji *et al.*, *Resource Geology 54*, 2004. |
| *South China Sea (GMGS-1)* | Fine-grained | | Zhang *et al.*, *FITI*, Fall 2007; Wu *et al.*, *ICGH 6*, Vancouver, 2008. |
| *Gumusut-Kapak, Malaysia* (Shell hazards evaluation) | Fractured fine-grained | | Hadley *et al.*, *Int. Pet. Tech. Conf. 12554*, 2008 |
| Gulf of Mexico<br>*Tigershark well: AC818*<br><br>*JIP Leg II: WR313*<br>*JIP Leg II: GC955* | <br>Sands<br><br>Sands<br>Sands | <br><br><br>Fractured fg<br>Fractured fg | <br>Boswell *et al.*, *Mar. Pet. Geol. 26*, 2009<br><br>Boswell *et al.*, *Initial Sci. Res. JIP Phase II*, NETL website, 2009 |
| ***Permafrost settings*** | | | |
| Messoyakha (inferred only) | Sands | | Collett & Ginsburg, *Int. J. Off. Pet. Eng. 8*, 1998. |
| *Milne Pt, Alaska: Mt. Elbert* | Sands | | Collett *et al.*, *Mar. Pet. Geol., 28*, 2011. |
| *Mackenzie Delta, Canada: Mallik* | Sands | | Dallimore and Collett., eds., *GSC Bull. 585*, 2005 |
| ***Intracontinental at mid-latitudes*** | | | |
| Tibetan Plateau | Fractured fine-grained | | Lu *et al.*, *Cold Reg. Sci. Tech. 66*, 2011. |
| Lake Baikal (only visually observed) | Turbidite sands | | Kuzmin *et al.*, *Int. J. Earth Sci. 89*, 2000 |

*Table 1: Generalized reservoir type (Figure 1) for modern gas hydrate drilling programs and for Messoyakha, categorized according to the gas hydrate resource pyramid in Figure 2. Except for Messoyakha, the classification is based on visual evidence and/or unequivocal pressure core or modern logging results consistent with the occurrence of gas hydrate at depths greater than 50 m below the seafloor (marine/lake) or tundra (permafrost) surface. Locations indicated in italics denote gas hydrate confirmed from logs and/or pressure cores, without visual observation.*

The map represents only a current snapshot and will evolve as more knowledge becomes available. For example, our understanding of northern Gulf of Mexico gas hydrate reservoir characteristics has evolved between the first DOE/Chevron JIP drilling in the Gulf of Mexico in 2003 (targeting largely fine-grained sediments) and the current phases of JIP drilling (targeting high saturation gas hydrates in sand-rich sediments; Boswell *et al.*, 2009). The Nankai Trough is another example of evolving understanding of a gas hydrate reservoir. ODP Leg 131 recovered gas hydrates in sands there, and the successful 1999-2000 MITI drilling used a variety of approaches to confirm the existence of gas hydrates at high-saturations in sandy deposits and to catalyze the establishment of the MH21 program in Japan. In 2004, METI drilled for several months and acquired more high quality logs and pressure core data, as well as visual confirmation of the gas hydrates.

Starting in early 2011, the USGS Gas Hydrates Project plans to overhaul its existing databases and compile a single, quality-controlled, fully-referenced master database of observed and inferred gas hydrate occurrences. This activity is part of the information management mandate of the USGS. The ultimate goal of this database effort will be to deliver authoritative, frequently-updated, tabular data and GIS-based maps to global users on a Web browser platform. The compilation of such a database will facilitate the refinement of existing types of gas hydrate maps and foster the development of new maps.

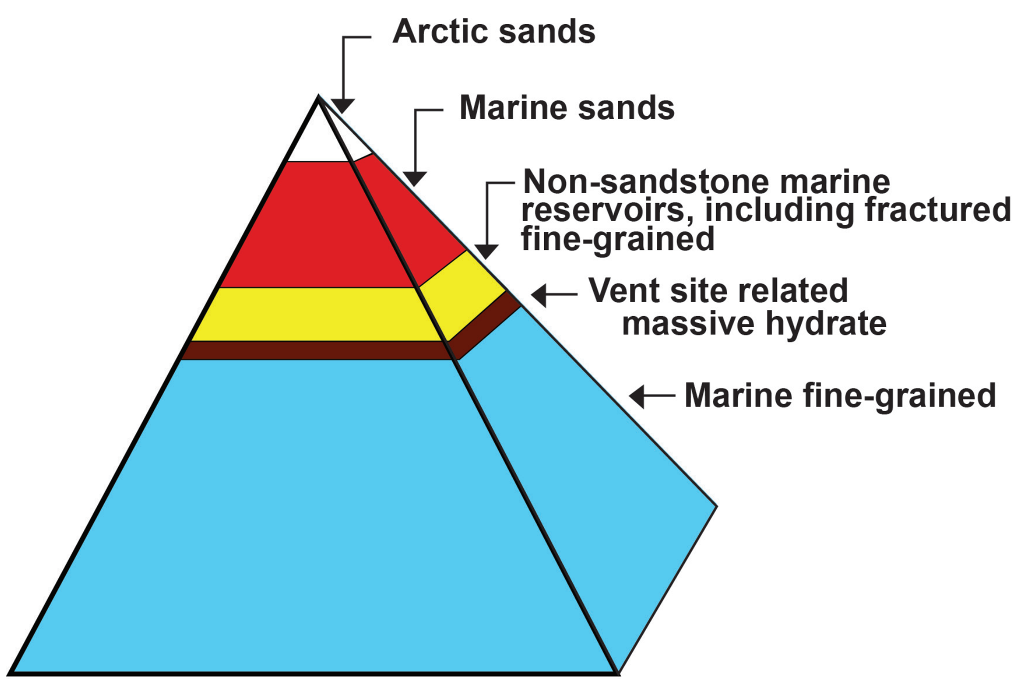


*Figure 2: Modified gas hydrate resource pyramid of Boswell and Collett (2006), color coded to match the categories used on the map in Figure 1.*

## USGS Gas Hydrates Project Convenes DOE Workshop on Climate-Gas Hydrates Interaction

*By Carolyn Ruppel (U.S. Geological Survey, Woods Hole, MA)*

About 20 U.S. scientists gathered in Boston on March 15 and 16, 2011 to discuss recent results from U.S. Department of Energy (DOE)-funded projects focused on the interaction of gas hydrates with the global climate system and to articulate research priorities for the next few years. University researchers and government scientists from DOE laboratories, the U.S. Geological Survey (USGS), and Naval Research Laboratory (NRL) participated in the presentations and discussions, and attendees included two young scientists who are current or former National Research Council/ DOE-National Energy Technology Laboratory Methane Hydrate Fellows.

The March 2011 workshop was the second such meeting organized by the USGS Gas Hydrates Project in coordination with DOE's National Energy Technology Laboratory. The first workshop, held in February 2008, included well-attended public talks at MIT and participant discussions on knowledge gaps in the study of climate-gas hydrate interactions. That spring, the National Methane Hydrates R&D Program issued a request for proposals to study the interaction of gas hydrates and the environment. The field-based and numerical modeling projects that were subsequently funded will mostly be completed within the current fiscal year. The projects conducted over the past few years have included field activities in the Gulf of Mexico, the Beaufort Sea, and offshore California and on the Alaskan North Slope. Numerical studies have focused on constructing global-scale models of processes related to gas hydrate formation and dissociation and on integrating gas hydrate dynamics into global climate models.

The March 2011 workshop provided an opportunity for participants to present detailed results from gas hydrates-related climate projects that were funded by DOE in 2008, conducted over longer time periods with support from several agencies (e.g., DOE, National Oceanic and Atmospheric Administration, and Minerals Management Service for the Mississippi Canyon 118 gas hydrates observatory), or, in some cases, supported largely by National Science Foundation's Office of Polar Programs. Additional funding by science mission agencies (e.g., the USGS) has also catalyzed research. Prior to these focused efforts, US research on the synergy between contemporary climate change and gas hydrate-related methane emissions was relatively obscure. The greater prominence now enjoyed by such research attests to the success of funding agencies and government and academic researchers in raising the profile of these studies, linking the research to global greenhouse gas initiatives, and coordinating with international groups, particularly in Europe (e.g., PERGAMON).

An important aspect of the workshop was the discussion of priorities for the next few years of climate-related gas hydrates research. As a starting point, it was agreed that the flux of methane from dissociating gas hydrates remains a critical unknown and of great importance for assessing the contribution of methane hydrates to annual global methane emissions. Equally important is the strength of sinks: how much methane from dissociating gas hydrates reaches the seafloor despite the strong anaerobic methane oxidation sink? How much escapes dissolution and oxidation in the water column and is eventually injected into the atmosphere? How much of the $CO_2$ produced by methane oxidation is eventually sequestered in carbonates?

The workshop participants agreed that the most climate-sensitive populations of gas hydrates should be the primary focus of field-based and modeling studies. These populations include gas hydrates associated with degrading subsea permafrost on shallow circum-Arctic shelves and gas hydrates located near the upper extent of gas hydrate stability on upper continental slopes. Monitoring in both space and time the dissociation/dissolution of near-seafloor gas hydrates (e.g., in the Gulf of Mexico) in response to a host of forcing factors will provide clues about the response of less accessible, more deeply buried gas hydrates to climate forcing. A few background sites where gas hydrate is stable under changing climate conditions should also be monitored to produce a comprehensive baseline for climate change-gas hydrates interactions. While it is important to focus on the contemporary to future fate of gas hydrates under climate warming scenarios, ice core and other paleo-studies will continue to provide critical data on the relative importance of gas hydrates, wetlands, and other methane sources during Pleistocene and Holocene warming events.

Numerical modeling of linked sediment-ocean-atmosphere processes related to gas hydrate dissociation, ebullitive emission of methane, and feedbacks in the ocean-atmosphere has advanced substantially in the past few years. However, researchers underscored that the ability to test models will remain limited due to the paucity of datasets to constrain (a) inventories of climate-susceptible gas hydrates; (b) spatial and temporal variability in methane emissions and methane sinks; and (c) the fate of methane bubbles within sediments and the water column. The current generation of models also has difficulty incorporating some types of geologic heterogeneities (e.g., faults, areas of rapid sedimentation and thus enhanced methane production). Given that such heterogeneities play an outsized role in the methane cycle, observational scientists and modelers must collaborate to devise appropriate ways to account for important heterogeneities.

**Suggested Reading**

Archer, D., Buffett, B., *et al.* Ocean methane hydrates as a slow tipping point in the global carbon cycle. Proceedings of the National Academy of Sciences 106, 20956-20601 (2009). doi:10.1073/pnas.0800885105.

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Petrenko, V., Smith, A.M., *et al.* $^{14}CH_4$ measurements in Greenland ice: investigating last glacial termination $CH_4$ sources. *Science* 324, 506-508 (2009). doi:10.1126/science.1168909.

Reagan, M.T. & Moridis, G.J. Dynamic response of oceanic hydrate deposits to ocean temperature change. *Journal of Geophysical Research* 113, C12023 (2008). doi: 10.1029/2008JC004938

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Solomon, E.A., Kastner, M., *et al.*, Considerable methane fluxes to the atmosphere from hydrocarbon seeps in the Gulf of Mexico. *Nature Geoscience* 2, 561-565 (2009). doi: 10.1038/NGE0574.

Wooller, M., Ruppel, C., *et al.* Permafrost gas hydrates and climate change: Lake-based seep studies on the Alaskan North Slope, *Fire in the Ice*, DOE/National Energy Technology Lab Gas Hydrates Newsletter, September edition, pp. 7-9 (2009). http://www.netl.doe.gov/technologies/oil-gas/publications/Hydrates/Newsletter/MHNewsSummer09.pdf

## Natural Gas Hydrate Sediment Cores Now Stored at Oregon State University

*Cores from 2005 Gulf of Mexico Gas Hydrate JIP Leg I in "D-tubes" stored in the Repository.*

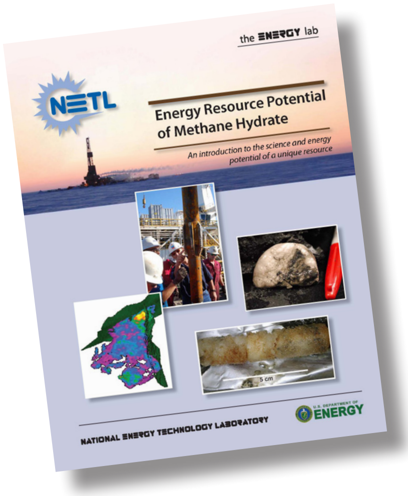
Since 2005, the National Methane Hydrate R&D Program managed by U.S. DOE/NETL has been heavily involved in coring expeditions in support of natural gas hydrate research worldwide. Providing geologic, physical, microbiologic, and geochemical information, these cores are critical to the research efforts of field scientists, experimentalists, and modelers. The Marine Geology Repository at Oregon State University (OSU) is a premier scientific facility, supported by NSF, whose purpose is to preserve geologic samples and provide the research community with access to them. The Repository has been in place since 1972 and houses a wide variety of over 15,000 samples. The collection includes over 5,000 sediment cores of all types, and the Repository continually accepts new samples.

NETL is working with OSU to suitably maintain sediment cores from natural gas hydrate systems and their accompanying reference datasets. The recent addition by NETL of a large, -10 °F walk-in freezer and a -86 °C ultra-low temperature freezer to the OSU facilities gives the Repository the capability to store samples and cores that must remain frozen for preservation, supplementing the Repository's existing 41,000 cubic feet of refrigerated storage space.

Sediment cores from natural gas hydrates systems currently at the OSU Repository include refrigerated cores from the 2005 Gulf of Mexico Gas Hydrate JIP Leg I expedition. Frozen cores from the BP-DOE Alaska North Slope Mount Elbert and from the 2010 MITAS expedition will also reside at the Repository. Curation information and reference datasets from these cores will be entered into the National Geophysical Data Center's Index to Marine and Lacustrine Geological Samples, where the information will be available to the scientific community. The excellent facilities of the Marine Geology Repository and the expertise of the Repository staff create an ideal environment for preserving geologic samples and providing access to samples and data, including "orphaned" or "stranded" cores that are looking for a long-term home.

For more information about the Marine Geology Repository please visit http://corelab-www.oce.orst.edu/ or contact corelab@coas.oregonstate.edu. Access to or samples from the gas hydrates related cores or any of the OSU collection can be requested according to the OSU Sample Distribution Policy http://corelab-www.oce.orst.edu/policy.html.

## Announcements




### Methane Hydrate Primer Now Available

NETL announces the release of "Energy Resource Potential of Methane Hydrate: An introduction to the science and energy potential of a unique resource." This primer provides regulators, policy makers, and the public with a balanced, comprehensive view of the historical development, current research, and environmental challenges associated with methane hydrate. The publication also describes the importance of methane hydrate in meeting the future energy needs of the United States, as well as issues related to the role played by methane hydrate in global climate change. To download the complete report, please visit:

http://www.netl.doe.gov/technologies/oil-gas/publications/Hydrates/2011Reports/MH_Primer2011.pdf

### 7th International Conference on Gas Hydrates begins July 17, 2011

The 7th International Conference on Gas Hydrates (ICGH 7) will take place in Edinburgh, Scotland, on July 17-21, 2011. ICGH 7 is the latest in a series of conferences held every three years since 1993. The conference encompasses all aspects of hydrate research; from fundamental physical properties, applied flow assurance, to global climate change, ICGH caters equally to both academia and industry. ICGH provides an excellent forum for participants to meet others with similar interests, and exchange ideas, expertise and experience, over the broad field of gas hydrates. Themes for the 2011 conference include: Gas Hydrate Fundamentals, Natural Gas Hydrates, Energy & Novel Technologies, and Extraterrestrial Gas Hydrates. There will be two special sessions focusing on Gas Hydrates & Global Climate Change and on Gas Hydrates & Flow Assurance. Please visit the conference website http://www.icgh.org/ for more details.

ICGH

## Opportunity for Organization of ICGH8 2014

The International Conference on Gas Hydrates (ICGH) takes place every three years in different countries around the world. It brings together a diverse group of scientists and engineers with a common interest in gas (clathrate) hydrates.

The first ICGH took place in New Paltz, New York (US) in 1993. The conference has since been held in Toulouse (France) in 1996, Salt Lake City (US) in 1999, Yokohama (Japan) in 2002, Trondheim (Norway) in 2005 and Vancouver (Canada) in 2008.

The location of ICGH8 2014 will be decided at ICGH7, Edinburgh (UK), 17th-21st July this year.

The ICGH7 Organizing Committee now invites proposals for the organization of the ICGH8 2014 conference. Proposals should contain:

(a) A short description of the proposed location of the conference

(b) A justification of why this location should be selected for ICGH 2014

(c) Outline plans for the program of the conference

(d) An estimate of registration fee

(e) A designated chair or co-chairs of the organizing committee for the conference

Each prospective organizing group will be invited to make an oral presentation of their plans to the current International Scientific Committee during ICGH7 2011.

A preliminary version of proposals for hosting ICGH8 2014 should be sent to G.K. Westbrook and B. Tohidi (co-chairs of ICGH7) at G.K.Westbrook@bham.ac.uk and Bahman.Tohidi@pet.hw.ac.uk by 31 May 2011. The preferred format of the proposal is PowerPoint-style presentation in a pdf document.

## Spotlight on Research

**KEITH HESTER**

Chemical Engineer,
ConocoPhillips

Keith Hester's interest in gas hydrates began while he was a student at the Colorado School of Mines (CSM) pursuing his degree in Chemical Engineering. "Dr. Dendy Sloan was my professor for thermodynamics during my junior year. I asked him about intern opportunities and he invited me to work in his lab over the summer," says Keith.

"Dr. Sloan also mentioned that he had a Ph. D. project looking at hydrates in the deep ocean through collaboration with colleagues in Monterey, California and asked if I wanted to study under him. I took that opportunity and never looked back." After completing his Ph. D. in Chemical Engineering from CSM in 2007, Keith participated in a two-year postdoctoral fellowship studying deep ocean hydrates at the Monterey Bay Aquarium Research Institute with Dr. Peter Brewer.

Currently, Keith is an associate engineer with ConocoPhillips in Bartlesville, Oklahoma where he is involved in experimental studies of $CO_2$ exchange with $CH_4$ hydrate. "The idea is to recover energy from natural hydrates, while sequestering $CO_2$ at the same time. Part of my work is in support of an upcoming hydrate field trial to test this technology on the North Slope in Alaska."

Keith feels that the most frustrating aspect of his research is the unpredictable nature of hydrates. "They always do what you don't expect them to do," he says. "That is also what makes the research rewarding. I love that hydrates involve so many different scientific disciplines and cover such a wide range of applications." He also believes that the most important challenge facing hydrates research lies in, "understanding natural hydrates better and how we can produce methane from natural hydrates for future energy."

Keith encourages aspiring hydrate researchers to be "open to new ideas and approaches to old problems. At the same time, hydrates have so many possible applications that there will always be something new to discover, so keep your eyes and your mind open. If something happens that you did not expect, take a moment to think about why it happened. These are the best moments to find out something new and exciting."

When he is not in the lab, Keith can be found engaging in a variety of other activities. "I have a passion for travelling and learning and interacting with people from other cultures. I am learning Italian and have started making mosaics. Also, I like to spend time outdoors–cycling, running, and being active."