METHANE HYDRATE NEWS

FIRE IN THE ICE

2017 Vol. 17, Issue 1

NATIONAL ENERGY TECHNOLOGY LABORATORY

Recovery of Thick Deposits of Massive Gas Hydrates from Gas Chimney Structures, Eastern Margin of Japan Sea: Japan Sea Shallow Gas Hydrate Project

R. Matsumoto[1], M. Tanahashi[1], Y. Kakuwa[1], G. Snyder[1], S. Ohkawa[1], H. Tomaru[2], and S. Morita[3]

[1]Meiji University, Japan
[2]Chiba University, Japan
[3]Advanced Industrial Science and Technology (AIST), Japan

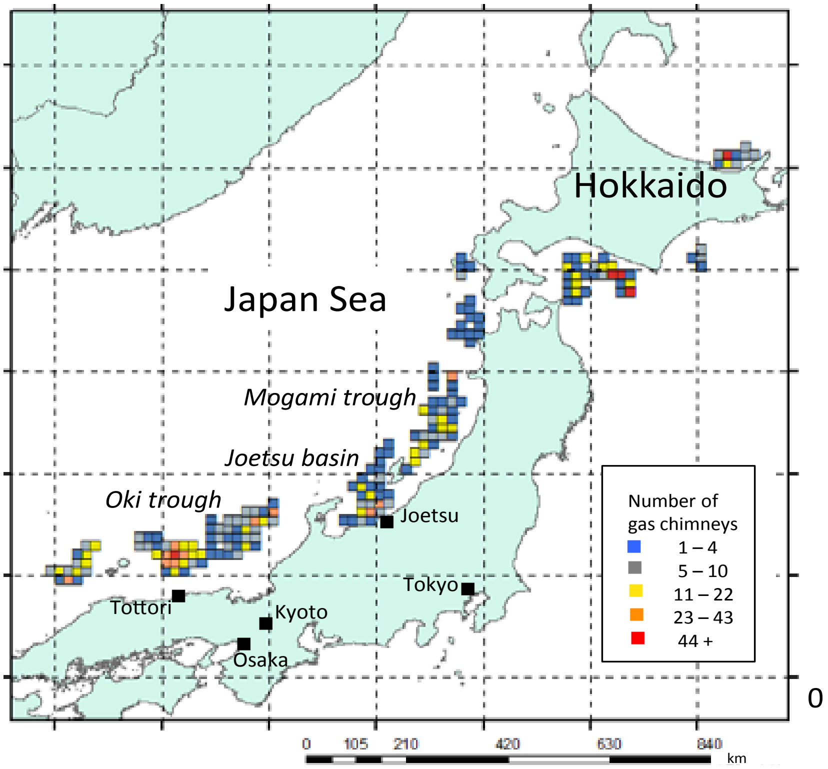

Figure 1. The three-year, national shallow gas hydrate program confirmed the presence of 1742 gas chimney structures in basins and troughs over 64,000 km² along the eastern margin of the Japan Sea and around Hokkaido. The distribution density is shown by the number of chimneys within a single grid block; each grid block is approximately 270 km² in area.

More than a decade of integrated efforts among scientists from academia, industry, national institutes, and government has shed light on the occurrence and formation of massive gas hydrates in the Japan Sea (e.g., Matsumoto, 2005; Hiruta et al., 2009; Matsumoto, 2011; Kakuwa et al., 2013; Hachikubo et al., 2015). These efforts have allowed a regional assessment of the enormous resource potential of these hydrate deposits (Figure 1).

CONTENTS

CONTACT

Ray Boswell

Geologist– Technology Demonstration and Innovation Center

412 386-7614

ray.boswell@netl.doe.gov

U.S. DEPARTMENT OF ENERGY

National Energy Technology Laboratory

1450 Queen Avenue SW
Albany, OR 97321
541-967-5892

420 L. Street, Suite 305
Anchorage, AK 99501
907-271-3618

3610 Collins Ferry Road
P.O. Box 880
Morgantown, WV 26507-0880
304-285-4764

626 Cochrans Mill Road
P.O. Box 10940
Pittsburgh, PA 15236-0940
412-386-4687

Visit the NETL website at:
www.netl.doe.gov

Customer Service:
1-800-553-7681

Fire in the Ice is published by the National Energy Technology Laboratory to promote the exchange of information among those involved in gas hydrates research and development.

This newsletter is available online at http://www.netl.doe.gov/research/oil-and-gas/methane-hydrates

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

This newsletter now reaches more than 1400 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 703-429-4841 or klang@keylogic.com

Shallow Gas Hydrates in Japan Sea

The Japan Sea originated through rifting of the eastern edge of Eurasia, followed by an eastward migration of the proto-Japan islands, approximately 25 to 15 million years ago. Tectonic inversion from extension to contraction occurred a few million years ago, resulting in thrust faulting and folding along the eastern margin of the Japan Sea. The tectonic evolution of the Japan Sea enhanced the maturation of organic matter, leading to the generation and upward migration of hydrocarbon gases to develop both gas hydrate accumulations and conventional hydrocarbon deposits.

Massive gas hydrates in the Japan Sea are not dispersed in sedimentary sequences but are instead concentrated within gas chimney structures. These structures are a few hundred meters to a kilometer in diameter and limited to sediment depths of approximately 100 meters (Figures 2 and 3).

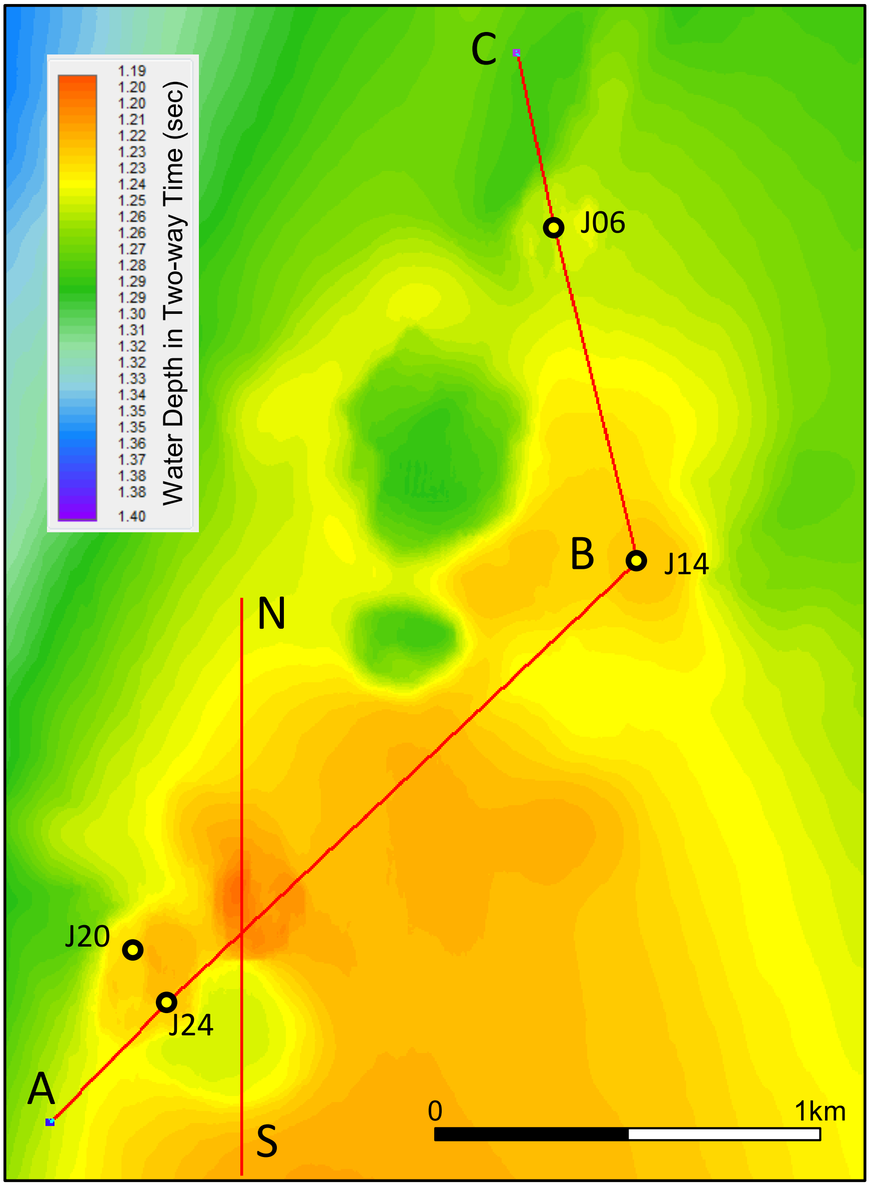

Figure 2. Clustered mounds and pockmarks in central Joetsu Basin. N-S and A-B-C transects indicate locations of the sub-bottom profile (SBP) shown in Figure 3, and the high-resolution 3D seismic profile shown in Figure 4, respectively.

Gas chimneys can be identified as zones of acoustic blanking on sub-bottom profile (SBP) images. However, 3D seismograms reveal stratified bedding within these gas chimneys, which distinguishes them from chimneys associated with mud volcanoes and diapirs. The chimney structures in the basin are interpreted to be efficient conduits for enhanced fluid migration through existing sediments.

Gas chimney structures may be recognized by their characteristic seafloor morphology. Two types of mounds have been observed, as well as pockmark depressions. The first type of mound forms a bathymetric high 2 to 10 meters above the adjacent seafloor and consists of uneven hard-ground, comprised of outcropping hydrates and carbonate crusts (Figure 3). This type of mound frequently hosts bacterial mats along with occasional methane seeps. The second type of mound is 5 to 10 meters high and consists of dome-shaped, stratified sedimentary sequences (Site J14 on Figure 4). Finally, chimneys may be topped by pockmarks, which are 5 to 15 meters deep (Figures 2 and 3).

Multi-beam echo-sounder (MBES) and SBP surveys in the basins and troughs of a 64,000 km² area along the eastern margin of the Japan Sea and around Hokkaido confirmed 1,742 gas chimney structures at water depths of 450 to 1500 meters (Figure 1). The distribution density of gas chimneys is variable in basins and troughs, ranging from < 5 to more than 50 of these structures in a grid block, which covers an area of approximately 270 square kilometers. Gas chimneys occasionally occur in closely-spaced areas, forming clusters of mounds and pockmarks (Figure 2).

Integrated Geophysical Surveys to Characterize Shallow Gas Hydrates

A high-resolution 3D seismic survey has revealed sharp velocity pull-ups of Bottom Simulating Reflectors (BSRs) within gas chimneys (Figure 4), suggesting that a significant amount of high-velocity material, perhaps massive gas hydrate, exists within these structures. The apparent depth to

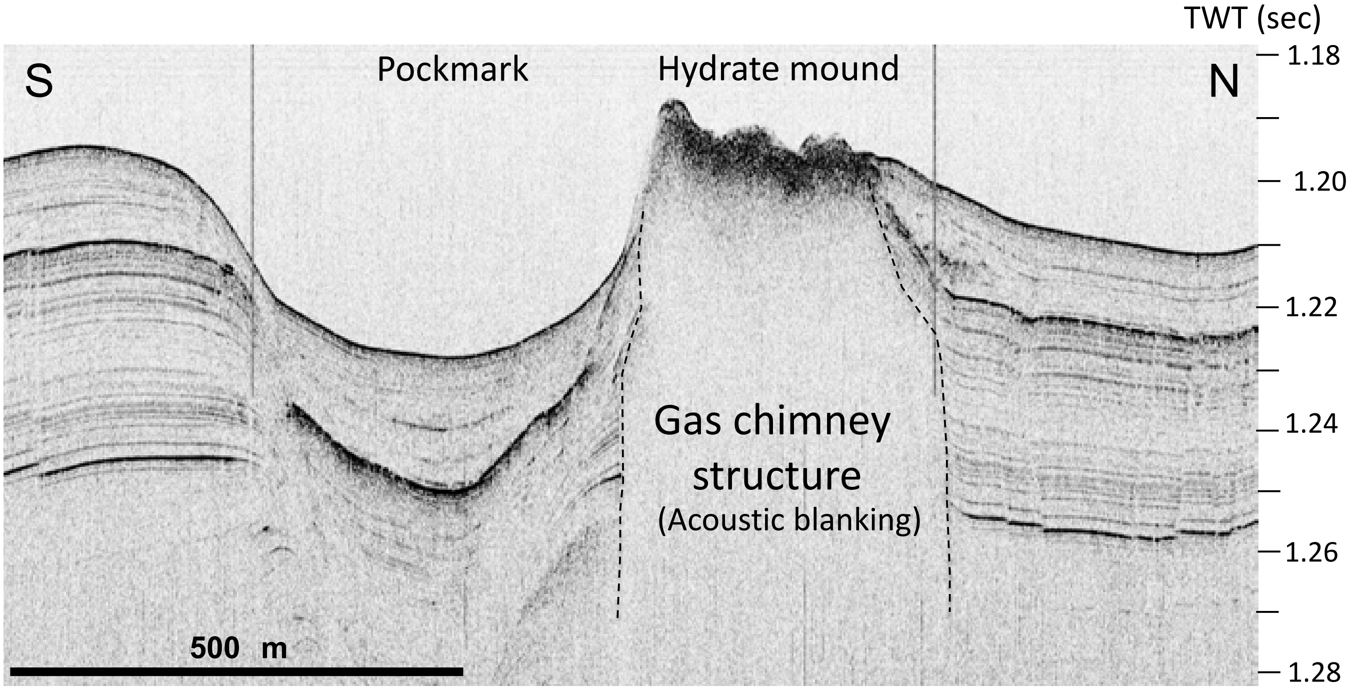

Figure 3. SBP over hydrate mound with uneven hard-ground and pockmark; survey data obtained by AUV-Urashima, JAMSTEC, during the expedition YK10-08 in 2010. The gas chimney structure is identified by the characteristic zone of acoustic blanking.

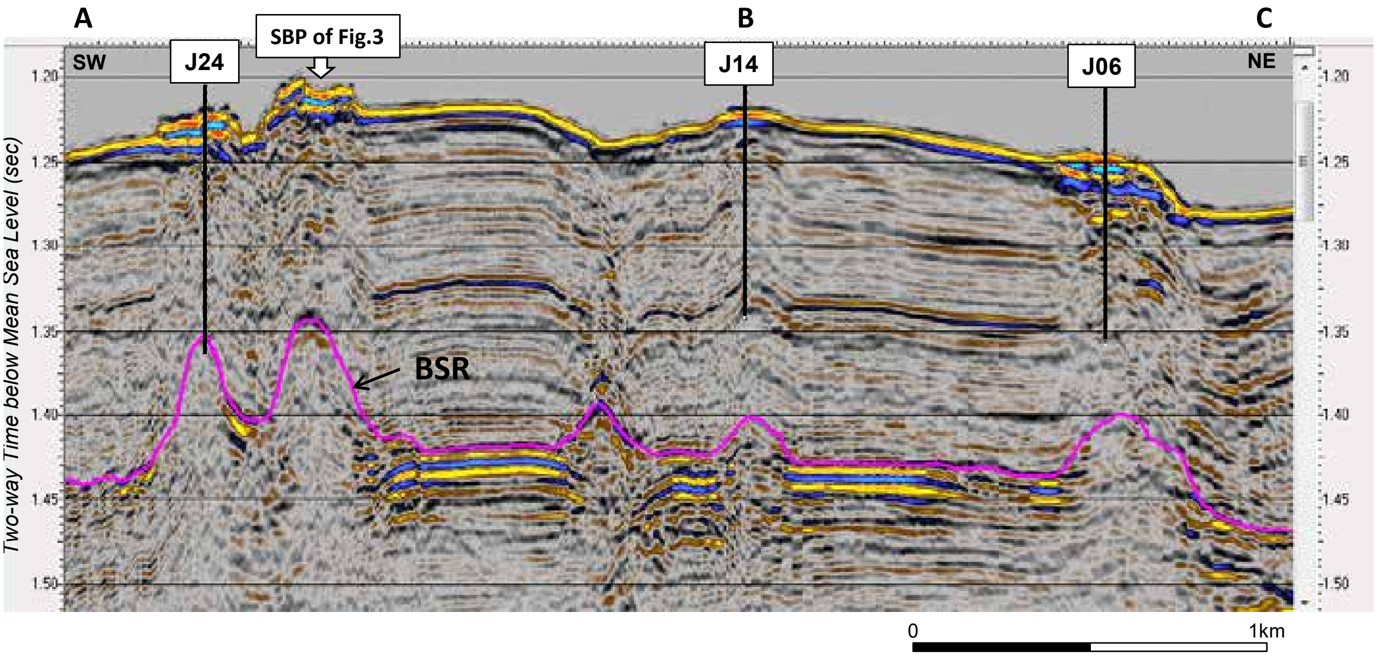

Figure 4. High-resolution 3D seismic profile obtained by 'Sound Array System' of Sound Oceanics, LLC, with 18 cables 150 meters in length, GI Gun of 210 cubic inches, and sampling rate of 0.5 milliseconds along the line A-B-C, shown in Figure 2. Note that stratified bedding is recognized within the gas chimneys, though variably disturbed and chaotic. The BSR in the gas chimneys appears at 0.12 to 0.14 second two way time (TWT), while in the surrounding sediments, BSR depth ranges from 0.20 to 0.22 second TWT below sea floor. The sharp pull-ups strongly indicate that high velocity material, perhaps gas hydrate, exists within the gas chimneys.

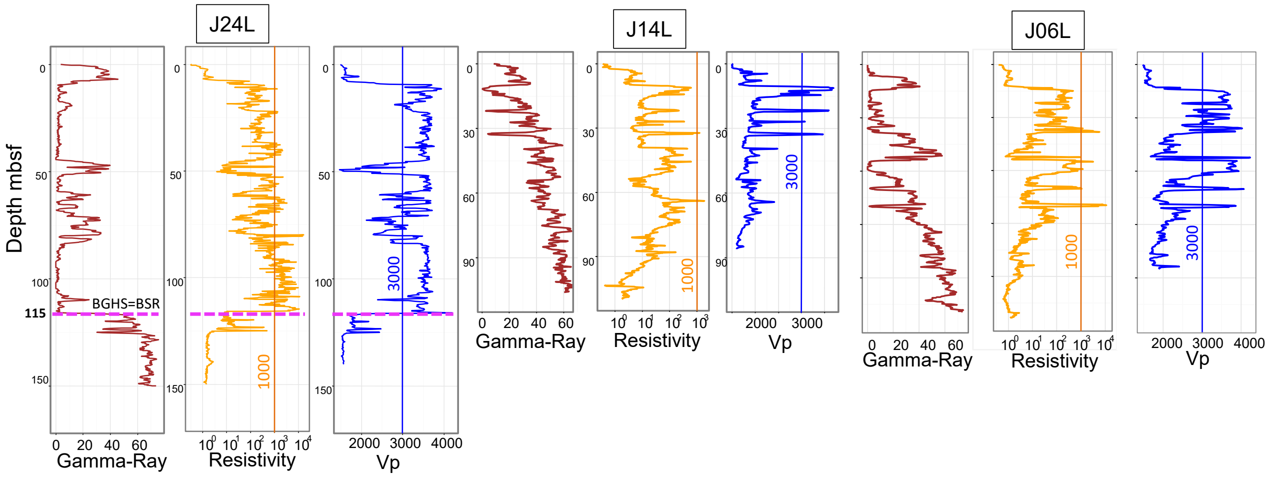

Figure 5. Logging-while-drilling (LWD) profiles at Sites J24, J14, and J06 on the HR 3D profile (Figures 3 and 4). The J24 hole was drilled on a mound with uneven hard-ground down to 150 meters below sea floor (mbsf), penetrating through BGHS at 115 mbsf. LWD profiles exhibit extremely low gamma-ray, high resistivity, 100 to 1000 ohm-meters, and high Vp values, 2500 to 3500 meters per second, indicating thick deposits of massive gas hydrate down to the BGHS. Hole J14, on the dome-shaped mound, and hole J06, on an uneven capped mound, also show significant anomalies suggesting thick massive hydrates down to 30 to 50 mbsf.

the BSR in gas chimneys ranges from 0.12 to 0.14 seconds two-way-time (TWT), while in the surrounding sediments, the depth ranges from 0.20 to 0.22 seconds TWT.

Logging-while-drilling (LWD) operations were conducted at 33 sites, including locations both on and off gas chimneys, using Schlumberger GeoVISION, ProVISION, NeoScope, SonicVISION (sonicSCOPE), and TeleScope tools. The base of the gas hydrate stability zone (BGHS) appears at around 100 to 120 meters below sea floor (mbsf), corresponding closely with theoretical predictions. Intensive LWD data on a hydrate mound with uneven hard-ground in the Joetsu Basin (Site J24 in Figure 4) revealed unprecedented, anomalous values of LWD parameters. These include: extremely low natural gamma-ray values, high resistivity values of 100 to 1000 ohm-meters, and high acoustic velocities of 2500 to 3500 meters per second down to the BSR (Figure 5). Observed LWD anomalies provide a strong indication that massive gas hydrate exists throughout gas chimneys above the BSR. Such high LWD anomalies and pull-ups of the BSR are also recognized in gas chimneys at Sites J14 and J06 (Figure 5).

Conventional and PCTB coring

Conventional coring operations near the extremely anomalous LWD sites retrieved thick, massive hydrate from several horizons (Figures 6 and 7). Six-meter core liners were recovered, which were full of massive aggregates of pure hydrate. The pure hydrate was associated with occasional, millimeter-thick clay intercalations (Figures 6 and 7), indicating that sediment particles were largely displaced during the growth of massive hydrate. Cores taken from the interval with modest LWD anomalies exhibit nodular to bedded hydrate of a millimeter to a few tens of millimeters, scattered in mousse-like to soupy sediments (Figure 8).

Geotek's 2-meter long Pressure Coring Tool with Ball Valve (PCTB) pressure coring system was deployed in multiple gas chimneys, allowing recovery of 27 undisturbed, pressurized hydrate-bearing cores. The cores were cut into 2 to 5 sections in Geotek's onboard Pressure Core Analysis and Transfer System (PCATS) for further experiments and geomechanical tests either onboard or onshore. Gases extracted from the hydrates were found to be composed of variable mixtures of thermogenic and microbial methane, with $\delta^{13}C$ of the methane ranging from -32 ‰ to -86 ‰ PDB-V.

Estimates of Gas Hydrate Amount

The amount of gas hydrates in a mound-gas chimney system in the Joetsu Basin (Figure 3), where 8 LWD and 9 coring holes were drilled, has been estimated from compressional wave velocity (Vp) anomalies and chloride anomalies observed in waters squeezed from conventional cores. These values were coupled with the results of quantitative slow degassing experiments using the PCTB. The results of the core analysis indicate that the average volume fraction of gas hydrates at each drill site is 35 to 86 volume% of the sedimentary sequences. However, the amount estimated from Vp anomalies is generally 10 to 20% lower than values estimated from the core analysis.

Summary

Marine gas hydrates often occur as fine, crystallized aggregates that fill interstices in sand layers, as reported from expeditions in the Nankai Trough, Gulf of Mexico, South China Sea, and offshore India. Such hydrated-sand reservoirs have until now been considered the prime target for exploration. Preliminary results from the integrated study of Japan Sea gas hydrates have shed light on the potential importance of shallow gas hydrates, but careful assessment of this new potential resource remains to be completed.

While the study of the Japan Sea gas hydrate resource was initiated by academic research, this article relied on information, especially with regard to the details of the drilling operations, from the Japan Sea Shallow Gas Hydrate Project 2013-2015 by the Ministry of Economy, Trade and Industry (METI) and the sub-commission from the National Institute for Advanced Industrial Science and Technology (AIST).

RECOMMENDED READING

Matsumoto, R., 2005. Methane plumes over a marine gas hydrate system in the eastern margin of Japan Sea: A possible mechanism for the transportation of subsurface methane to shallow waters. Proceedings ICGH-5, Trondheim, pp. 749-754.

Snyder, G.T., Hiruta, A., Matsumoto, R., Dickens, G.R., Tomaru, H., Takeuchi, R., Komatsubara, J., Ishida, Y., and Yu, H., 2007. Pore water profiles and authigenic mineralization in shallow marine sediments above the methane-charged system on Umitaka Spur, Japan Sea. Deep-Sea Research II, v. 11-13, pp. 1216-1239.

Matsumoto, R. and others, 2009. Formation and collapse of gas hydrates deposits in high methane flux area of the Joestu basin, eastern margin of Japan Sea. Journal of Geography, v. 118, pp. 43-71.

Hiruta, A., Snyder, G.T., Tomaru, H., and Matsumoto, R., 2009. Geochemical constraints for the formation and dissociation of gas hydrate in an area of high methane flux, eastern margin of the Japan Sea. Earth and Planetary Science Letters, v. 279, pp.326-339.

Matsumoto, R., Lin, S., Pecher, I., Riedel, M., Ryu, B-J., Lee, S-R., Sain, K., and Wu, S., 2011. Occurrence and exploration of gas hydrate in the marginal seas and continental margin of the Asia, India, and Oceania region. Marine and Petroleum Geology, v. 28, pp. 1-35.

Kakuwa, Y., Nakajima, T., Kumon, F., Matsumoto, R., Nakamura, Y., Oi, T., Tomiyama, T., and Machiyama, H., 2013. Description of sediments recovered during the cruise of MD179 in the Japan Sea- Umitaka Spur and its surrounding area, off Joetsu. Journal of the Japanese Association for Petroleum Technology, v. 78, pp. 97-103.

Figure 6. Coring operation for the 2015 campaign was conducted by GeoTek Ltd. The photo shows the recovery of hydrate on deck from about 22 mbsf at Site J24.

RECOMMENDED READING CONT.

Tomaru, H. and others, 2015. Geochemistry of the interstitial waters of cores from gas hydrate exploration in the eastern margin of Japan Sea. Journal of the Japanese Association for Petroleum Technology, v. 77, pp. 262-267.

Hachikubo, A., Yanagawa, K., Tomaru, H., Lu, H., and Matsumoto, R., 2015. Molecular and isotopic composition of volatiles in gas hydrates and in sediment from the Joetsu Basin, eastern margin of the Japan Sea. Energies, v. 8, pp. 4647-4666.

Figure 7. Thick, massive hydrates recovered from 17 mbsf at Site J20, about 150 meters northwest of Site J24. Pure hydrate cores were X-ray CT scanned and dissociated onboard to recover hydrate gases, hydrate water, and insoluble residues in the hydrates. Samples were then stored in liquid nitrogen.

Figure 8. Nodular and lenticular hydrate aggregates in mousse-like mud recovered from 23.5 mbsf at Site J06. Hydrate aggregates seem to develop horizontally along bedding planes.

GMGS4 Gas Hydrate Drilling Expedition in the South China Sea

Yang Shengxiong[1], Liang Jinqiang[1], Lei Yong[1], Gong Yuehua[1], Xu Huaning[1], Wang Hongbin[1], Lu Jingan[1], Melanie Holland[2], Peter Schultheiss[2], Wei Jiangong[1], and the GMGS4 Science Team

[1] Guangzhou Marine Geological Survey, Guangzhou, China
[2] Geotek Ltd, Daventry, UK

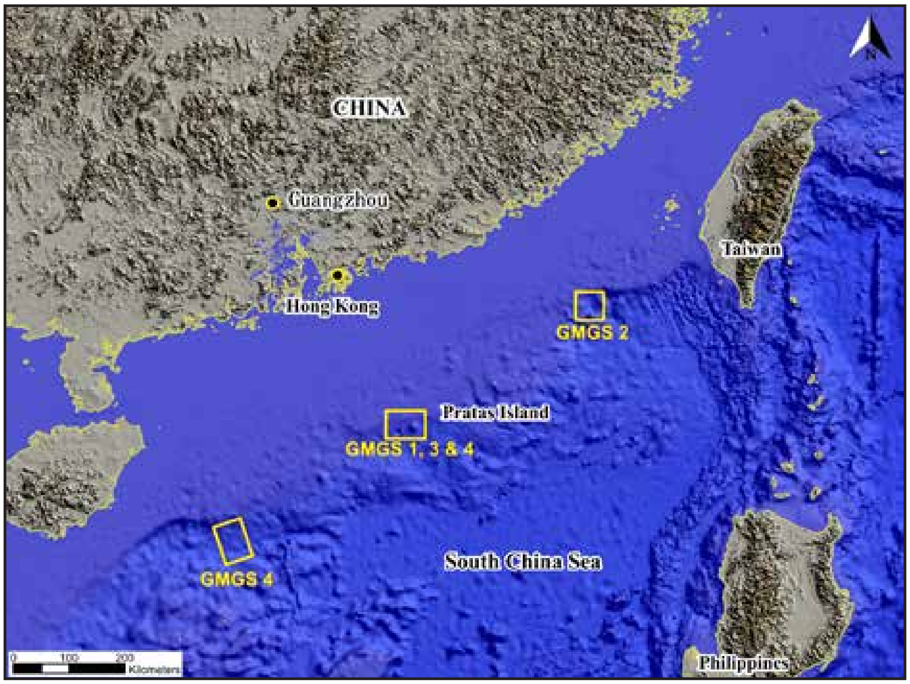

Figure 1. Locations of GMGS1, GMGS2, GMGS3, and GMGS4 in the South China Sea.

Introduction

During April to August 2016, China's Geological Survey/Guangzhou Marine Geological Survey (CGS/GMGS) drilled and cored sites in the South China Sea in the Shenhu and Xisha Sea areas. Logging-while-drilling (LWD) data were collected, conventional and pressure cores were analyzed, and *in situ* piezocone measurements were made to assess permeability and strength parameters of hydrate-bearing sediments. Drilling at Shenhu confirmed the 2015 GMGS3 findings that concentrated gas hydrate exists in clay-rich silt layers 20-90 meters thick, and that some regions of Shenhu show evidence of Structure II hydrate and recent hydrate formation.

China's GMGS4 Expedition in Context

GMGS4 was the fourth gas hydrate drilling expedition in the South China Sea. Three prior expeditions, GMGS1 through GMGS3, explored both the center (Shenhu) and the eastern part of the Pearl River Mouth Basin (Figure 1). The GMGS2 drilling area is a region of focused flow and high methane flux, containing old and new vent sites with visible gas hydrate in veins and layers. The Shenhu area, in contrast, has gas hydrate finely distributed within a silty matrix, in layers tens of meters thick. Some results of the GMGS2 and GMGS3 Expeditions can be found in prior issues of this newsletter (see FITI, Vol. 14, Iss. 1 and FITI, Vol. 15, Iss. 2).

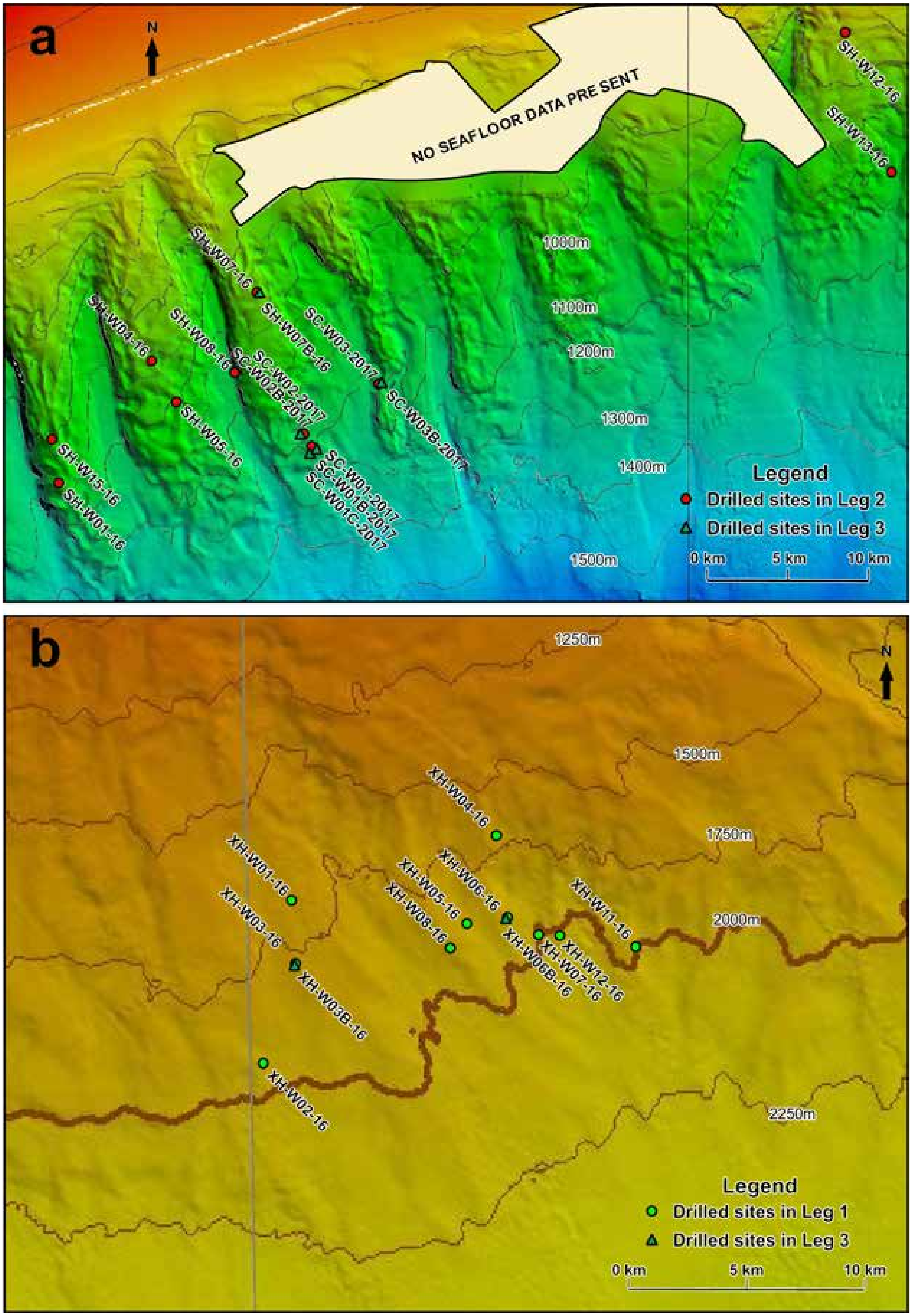

Figure 2. a) Locations of sites drilled in the Shenhu area. b) Locations of sites drilled in the Xisha area.

GMGS4 Drilling & Coring

Expedition GMGS4 took place on the Fugro Voyager with its R100 drill rig. Fifty-eight days of LWD operations allowed the collection of downhole data from 21 sites. Eleven of these sites were at the Shenhu area, in water depths ranging from 793 to 1292 meters, and penetrated depths from 178 to 297 meters below the seafloor (mbsf). Ten sites were drilled at the Xisha area, in water depths of 1700 to 1960 meters, with penetrations of 309 to 618 mbsf (Figure 2). The Schlumberger LWD tools used included the *GeoVISION, NeoScope, SonicScope (SonicVision)*, and *ProVision* tools which provide logs of gamma ray, resistivity, density, and neutron data, as well as resistivity image and compressional and shear-wave velocities.

Four sites at Shenhu and two sites at Xisha were selected for coring and *in situ* testing. Locations were cored using the Fugro Hydraulic Piston Corer (FHPC) and the Fugro eXtended Marine Core Barrel (FXMCB) as well as Geotek Coring's Pressure Coring Tool with Ball Valve (PTCB). Core analysis at sea included Geotek's Pressure Core Analysis and Transfer Equipment (PCATS) for analyzing pressure cores up to 3.5 meters long and the PCATS Triaxial equipment for performing geomechanical tests on samples recovered at full *in situ* hydrostatic pressures. Standard geochemical and gas analyses were also carried out by Geotek. *In situ* testing of pore pressure dissipation, temperature, and cone strength were performed using Fugro's combined Temperature-Piezocone Penetrometer Tool (TPCPT).

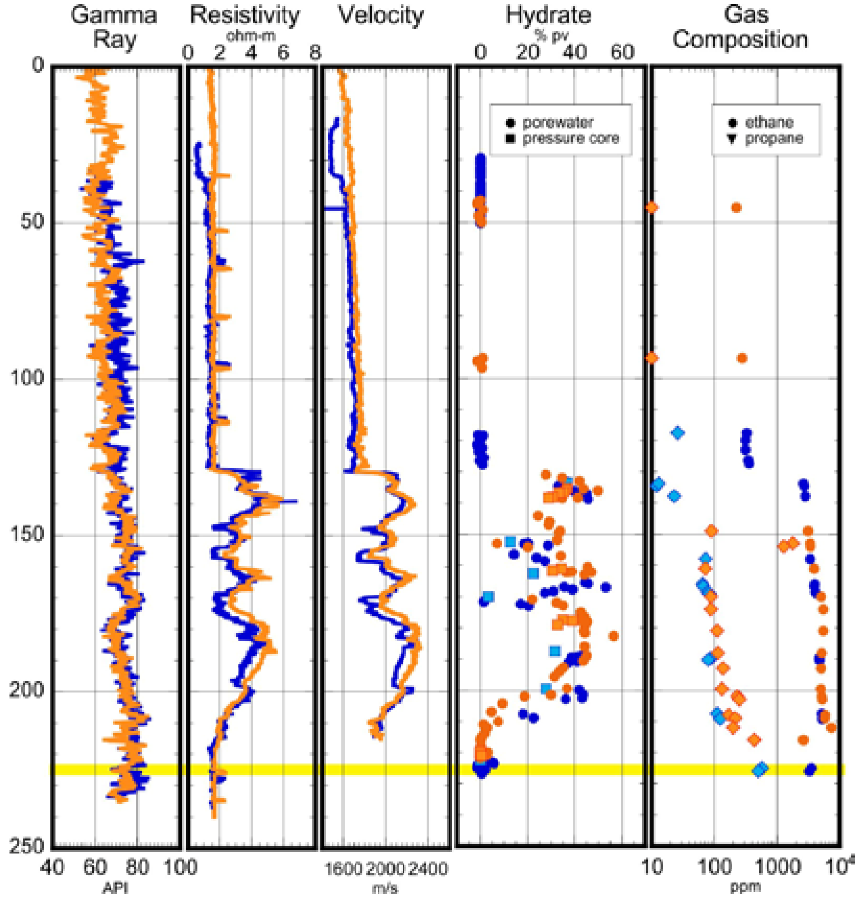

Figure 3. Comparison of LWD data, gas hydrate concentration, and gas composition from 2015 (blue) and 2016 (orange) at Site SC-W03-2017. Note that depths are shifted by 16.5 m on the 2015 data. Yellow horizon is the calculated base of methane hydrate stability.

GMGS4 Preliminary Results

The main focus of the Shenhu drilling and coring was at sites SC-W01-2017, SC-W02-2017, and SC-W03-2017 (see Figure 2a). LWD holes were drilled nearby the original sites cored on Expedition GMGS3 to determine the homogeneity of the reservoirs. Coring at these sites replicated the findings from Expedition GMGS3, thereby providing good confidence in the data. A fourth coring site at Shenhu also proved to contain a concentrated gas hydrate zone.

In situ testing was used extensively during Expedition GMGS4 to determine the strength and permeability of the Shenhu sediments. Gas hydrate-bearing sediments at Shenhu had higher strengths (~10x) than similar non hydrate-bearing sediments. Permeability, as measured *in situ* using the piezo cone, was relatively low at all sites and varied between 0.4 and 40 millidarcies. There was no evidence of a systematic change in permeability between hydrate-bearing and non hydrate-bearing sediments.

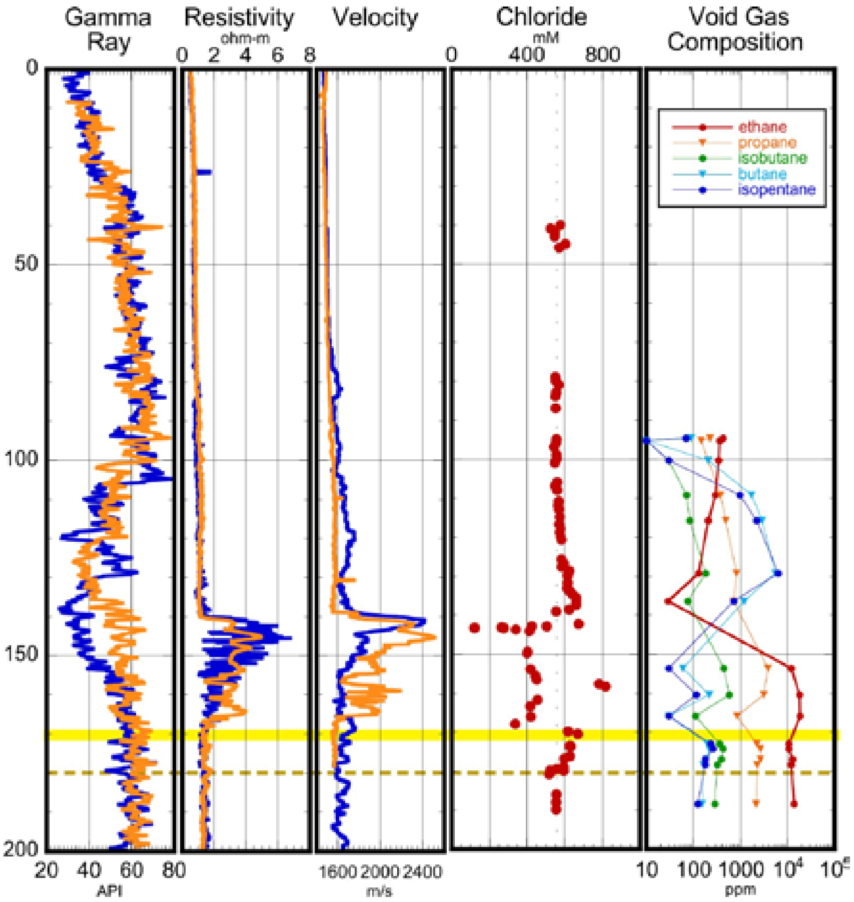

Figure 4. Comparison of LWD data from 2015 (blue) and 2016 (orange) at Site SC-W02-2017. Note that depths are shifted by 5.7 m on the 2015 data. Chloride and gas concentration data for 2016 are also shown. Yellow horizon is calculated base of methane hydrate stability. Brown dashed line is depth of pressure core mentioned in text. Black dotted line is a vertical aid for the eye.

While all three re-drilled sites had hydrate distributions similar to those measured in 2015, the degree of lateral variability between sites varied (see Figures 3 and 4). Site SC-W03-2017 was extremely similar to its companion 2015 site in all measured properties. Site SC-W02-2017 (Figure 4) and nearby Site SC-W01-2017 (not shown), in contrast, showed overall similarities in hydrate distribution, but neither the resistivity logs nor the gamma ray logs were replicated with the fidelity of Site SC-W03-2017.

Note:

*STP = standard temperature & pressure (0˚C, 1 bar = 0.1 MPa)

One interesting conclusion from this lateral exploration is that the low gamma ray sediments, in this case carbonate- rather than quartz-bearing sediments, do not control the presence of gas hydrate in these Shenhu sediments (Figure 4).

Two of the sites revisited had evidence of recently active hydrate formation and Structure II gas hydrate. Figure 4 shows data from one of these sites (SC-W02-2017). The pronounced increase in chloride concentration above and below the concentrated gas hydrate zone, as defined by the resistivity anomaly, attests to recent salt exclusion due to gas hydrate formation. At the same site, a pressure core with excess gas (~40 L @ STP* per meter of core) was collected (dashed line in Figure 4) 10 m below the calculated base of methane hydrate stability (solid line in Figure 4). As there were no low sonic velocities associated with this sample in the LWD data or in PCATS, there is no evidence that this was free gas *in situ*. Based on the gas composition (over 2000 ppm propane), the gas was more likely to be contained in Structure II hydrate. This sample was calculated to have 10 % gas hydrate as a percentage of pore volume.

The locations drilled in the Xisha area were exploratory in nature, and though none of the ten LWD data sets showed evidence of gas hydrate, two sites were cored to better understand the lithology. While the bulk of the sediments were clay-rich, a series of intriguing hard chalky layers were encountered at one site near 500 mbsf, and these will be further examined in the 3D seismic data sets.

After more than 3 months of drilling and testing, GMGS4 provided important geophysical, geochemical, and geological data in the South China Sea. The results showed that the Shenhu area might be a good candidate site for potential production testing in the future.

HYDRATE EVOLUTION IN RESPONSE TO ONGOING ENVIRONMENTAL SHIFTS

Alan Rempel[1], Julia Irizarry[1], Brandon Vanderbeek[1], and Alexander Handwerger[2]

[1] Department of Earth Sciences, University of Oregon
[2] Jet Propulsion Laboratory, Pasadena, California

Introduction

Arctic climate change has attracted increasing attention in recent years, as observations of thawing permafrost and changes in sea ice cover have gained prominence. Less visible, but potentially more widespread, are the consequences of melting and dissolution in hydrate reservoirs in response to ongoing environmental shifts. This recognition motivated the two-year DOE/NETL funded Hydrate Evolution in Response to Ongoing Environmental Shifts (HEROES) project at the University of Oregon.

Predictive Models of Methane Solubility

Recognizing important perturbations that pore-scale phenomena can exert on hydrate stability, Irizarry conducted MS research to develop predictive models to describe changes in methane solubility with hydrate saturation level and sediment characteristics. The left panel of Figure 1 is a schematic depiction of hydrate–liquid phase behavior in an idealized pore. Residual liquid with elevated methane solubility remains in high-curvature interfacial zones near particle contacts, connected by thin aqueous films coating mineral surfaces. Increases in hydrate saturation enhance the interfacial curvature and reduce the film thickness, requiring further increases to the aqueous-phase methane solubility.

To advance beyond previous two-dimensional, idealized descriptions of pore-space geometry, Irizarry used Monte Carlo integration techniques. Her approach assesses local equilibrium conditions at a large number of

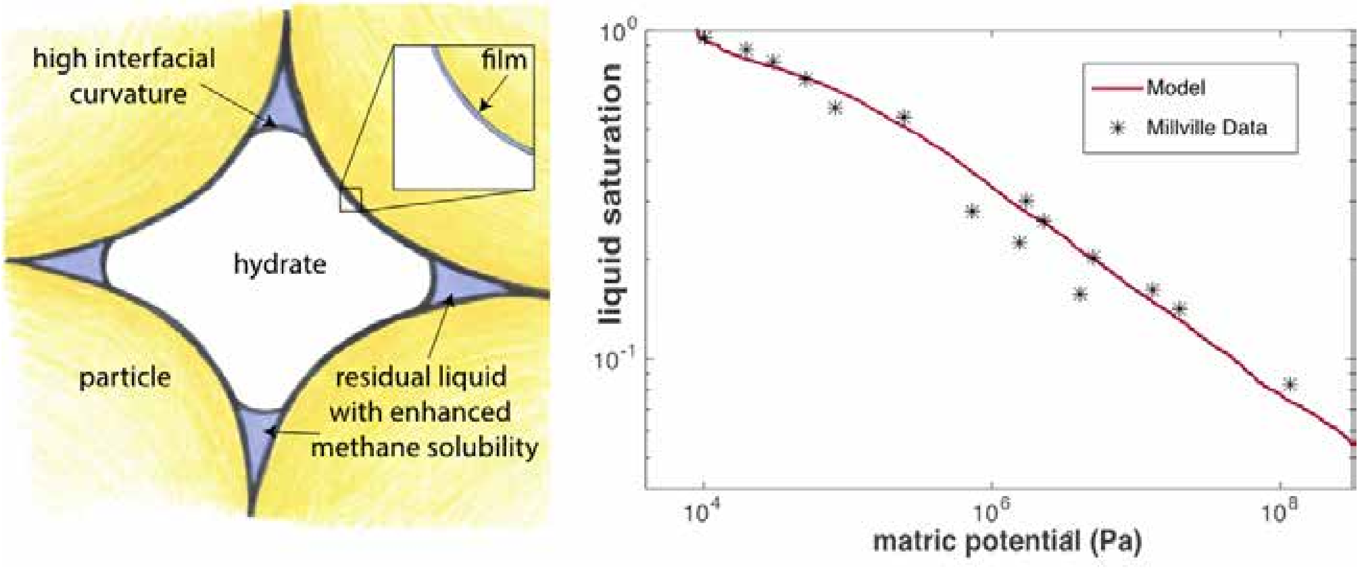

Figure 1. Left: Schematic depiction of hydrate–liquid coexistence within the hydrate stability zone. Right: Model dependence (red line) of residual liquid saturation as a function of matric potential, compared against data (points) from vadose-zone measurements on Millville silt-loam.

points within media constructed from a packing algorithm. The algorithm is designed to accommodate user-defined particle-size distributions. Successful validation tests (e.g., Figure 1, right panel) compare model results to published analog results from ice saturation experiments and vadose-zone measurements. Both systems are similarly affected by surface energy and wetting effects, and the close agreement between the model and the observed data provides confidence in the predictive power of the model.

Hydrate Distribution Modeling

The solubility contrasts that occur at stratigraphic boundaries, due to abrupt changes in pore size, can lead to formation of high-saturation hydrate anomalies in the more coarse-grained material. Moreover, these high-permeability sediments allow for increases in the advective flux of dissolved methane, which contributes to enhanced hydrate saturation levels.

Vanderbeek has developed a model that accounts for these effects and predicts the distribution of hydrates as a function of burial depth, sedimentation rate, biogenic production, background fluid flux, and permeability and solubility contrasts across dipping layers (see Figure 2). By improving our understanding of the controls on hydrate distribution in sediments, this model lays the groundwork for planned efforts using inverse methods to extract information on less well-constrained hydrate reservoir parameters. Such parameters include biogenic production rates, sedimentation histories, and fluid transport.

Effects of Hydrate Growth and Loss in Sediments

The destabilization of high-saturation hydrate anomalies can have hazardous consequences. As hydrate anomalies grow, they can displace the surrounding sediment grains and reduce the effective stress that

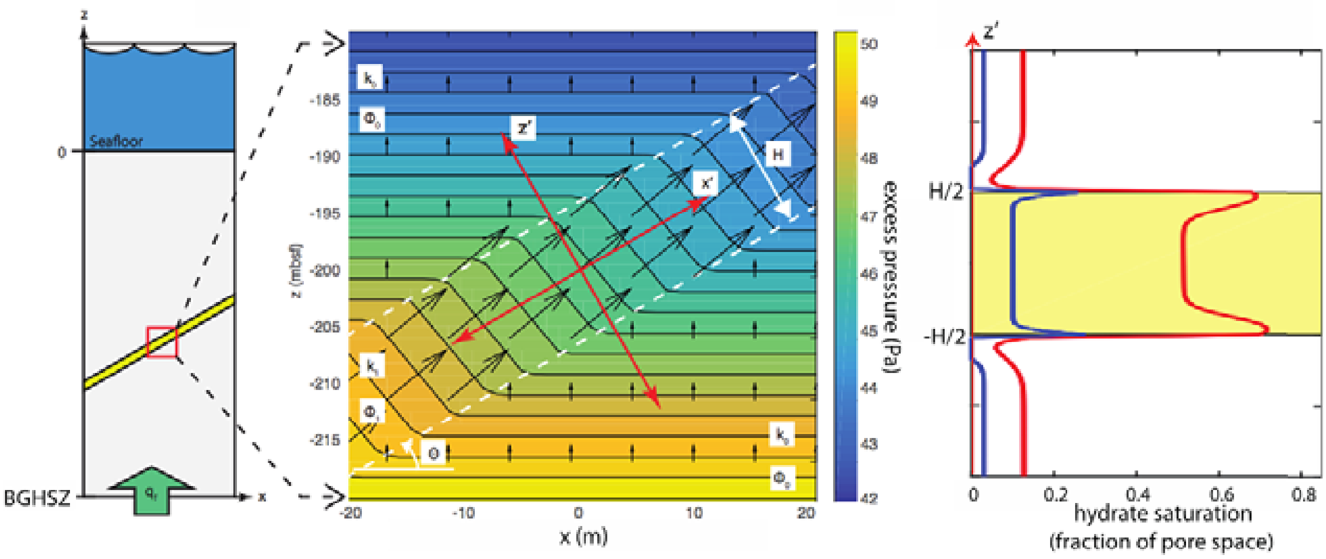

Figure 2: Mechanisms for hydrate anomaly formation in a dipping, coarse-grained layer. Arrows (middle panel) depict enhanced fluid flux due to permeability increase. Blue and red curves (right panel) show hydrate saturation across the layer, corresponding to different accumulation times (for example, caused by different sedimentation rates). Peaks on coarse-layer boundaries are supplied by diffusive transport from fine-grained material with higher methane solubility.

SOURCES AND SUGGESTED READING

Handwerger, A.L., Rempel, A.W., Skarbek, R.M., Roering, J.J., and Hilley, G.E., 2016. Rate-weakening friction characterizes both slow sliding and catastrophic failure of landslides. Proceedings of the National Academy of Science, 113, pp. 10,281–10,286.

Irizarry, J.T. and A.W. Rempel, A.W., 2014. How methane solubility changes with hydrate saturation, pore size, and salt content in polydispersed media. Proceedings of the 8th International Conference on Gas Hydrates (ICGH8-2014), Beijing, China, 18 July–1 August, 2014.

Rempel, A.W., 2011. A model for the diffusive growth of hydrate saturation anomalies in layered sediments. Journal of Geophysical Research–Solid Earth, 116, p. B10105.

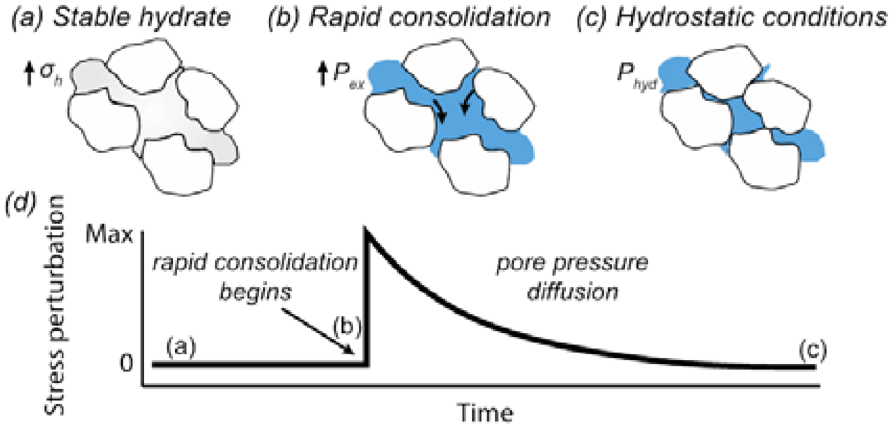

Figure 3: Conceptual model for rapid consolidation of sediment grains following removal of the hydrate phase. White polygons represent individual sediment grains, gray polygon is a high-saturation hydrate anomaly, pore water is blue. (a) High-saturation hydrate anomalies partially support overburden, reduce effective stress, and prevent normal consolidation. (b) Hydrate destabilization leads to rapid consolidation and the development of excess pore pressures. Black arrows indicate that sediment consolidation has begun. (c) Excess pore pressure diffuses away and tends towards hydrostatic conditions. (d) Stress perturbation time series showing rapid development of excess pore pressure and pore pressure diffusion to hydrostatic conditions.

sediment contacts support. This can lead to an under-consolidated configuration that is poised for rapid consolidation and development of excess pore fluid pressures upon removal of the hydrate phase (Figure 3).

At the same time, the loss of hydrate causes the effective cohesion, due to pore-bridging hydrate, to be reduced dramatically. While completing his PhD at Oregon, Handwerger, now a NASA Post-Doctoral Researcher at the Jet Propulsion Laboratory, developed models to examine conditions under which hydrate loss can weaken submarine slopes enough to either trigger landslides directly or increase their vulnerability to external perturbations (e.g. earthquake shaking). In cases where sliding initiates, Handwerger's model accounts for the influence of rate-and-state dependent friction and elastic coupling to determine whether to expect gradual slumping or catastrophic failure. A detailed account of this work is currently under review.

Changes in environmental conditions, whether occurring naturally or associated with resource extraction efforts, can destabilize hydrate anomalies and promote hazardous methane release. A multi-scale modeling approach provides useful, quantitative insight into the dominant controls on the stability of hydrate systems and potential modes of disruption.

LAMINAR VERSUS MASSIVE NATURE OF HYDRATE-BEARING SANDS IN WELL GC955-H: INSIGHTS FROM ROCK PHYSICS MODELING

Jiliang Wang[1], Priyank Jaiswal[2], Shiguo Wu[1]

[1] Institute of Deep Sea Science and Engineering, Chinese Academy of Sciences, China
[2] Boone Pickens School of Geology, Oklahoma State University, USA

In the absence of coring, which is the most reliable way of verifying the presence of hydrate, geophysical measurements are the next best hydrate proxy. Within the geophysical domain, sonic and resistivity are the two most commonly used hydrate indicators. Within a sedimentary horizon that produces consistent background values in the geophysical logs, increases in resistivity and/or sonic velocity may be interpreted as indicators of increasing hydrate saturation. However, sonic or resistivity enhancement is not linearly proportional to the amount of hydrate saturation. Hydrate morphology, including grain arrangements and mechanical interactions, also plays a key role, and both sonic and resistivity measurements respond to some degree to these factors. However, because resistivity and sonic measurements are made at different resolutions, they respond differently to hydrate distribution in sediments. Resistivity has finer vertical resolution while sonic is more susceptible to morphology.

Here we analyze data from Well H located in leased block Green Canyon 955 (GC955) site, drilled during the Gulf of Mexico JIP Leg 2 expedition, which targeted a sand-rich unit. Several types of Logging-while-drilling (LWD) data, such as gamma-ray, density-porosity, resistivity, sonic and caliper, were acquired in Well H (Figure 1). In the sand-rich interval, resistivity and sonic velocities showed clear enhancement affirming presence of hydrate. No geophysical evidence indicated an underlying free gas layer.

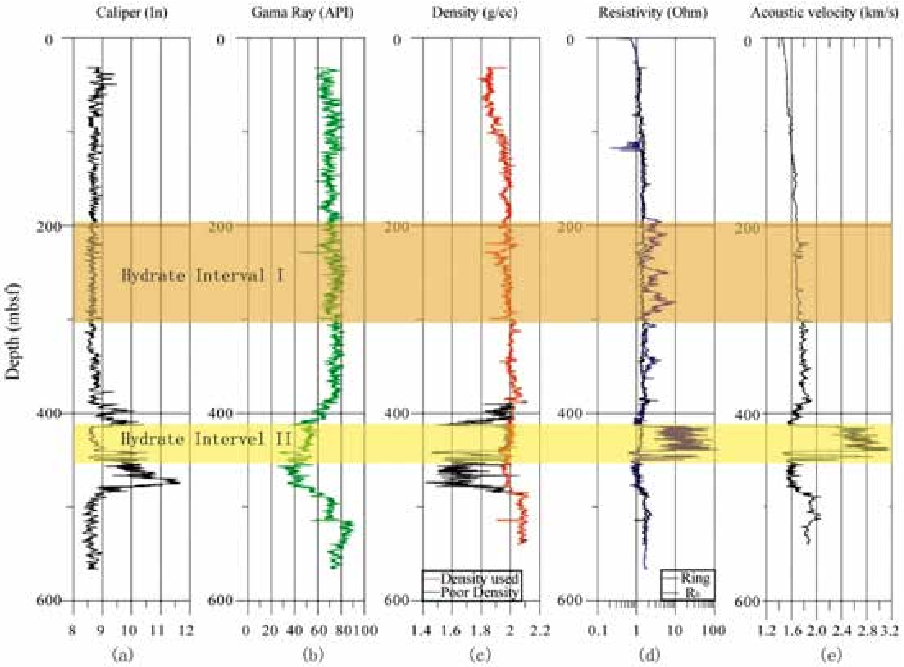

Figure 1. LWD data from hole GC955H. a) Caliper, b) gamma-ray, c) density, d) resistivity, and e) sonic. Two hydrate intervals are inferred, mainly based on the resistivity data. Hydrate Interval I occurs in fine-grained sediment. Hydrate Interval II occurs in sand-rich sediment and is the focus of this study. Caliper data show significant washout in Interval II. Density in the washed-out zone (red curve) is corrected to account for anomalously high values. In (d) ring resistivity is compared with background hydrate-free resistivity (R_0).

To deduce hydrate morphology and saturation from the resistivity and sonic data, a series of assumptions were made. The caliper log recorded several instances of borehole washouts within the sandy units, which we interpreted as an absence of hydrate. Our first assumption is that when hydrate is present, it binds sediment grains together, and, therefore, a unit becomes mechanically less stable without hydrate. Making this assumption automatically implies that the sandy unit cannot be treated as a homogeneous medium with evenly dispersed hydrate. Instead, it must be treated as a layered medium comprised of hydrate-rich and hydrate-poor units.

Next, we take a closer look at the resistivity logs. Resistivity data were collected using two tools – *GeoVISION* and *EcoScope*. The *GeoVISION* tool measures resistivity using four source-receiver arrangements referred to as the shallow, medium, deep, and ring, with comparable vertical resolutions (5–7.5 cm) but increasing depth-of–penetration (2.5, 5, 7.5, and 17.5 inches, respectively; Schlumberger, 2007). The EcoScope tool, on the other hand, averages a larger volume of the earth for resistivity measurements. It acquires data with three source-receiver arrangements, referred to as A16L, A28L, and A40L, with a vertical resolution of 41, 71, and 100 cm, respectively, and penetration depths ranging from 130 to 175cm (Schlumberger, 2008).

In Hole H, characteristic separation of the three kinds of *EcoScope* resistivity, which is often caused by invasion of drilling fluids, is not obvious. Further, ring resistivity is higher than A40L (Figure 3). This forms the basis of our second assumption– that ring resistivity is not influenced by borehole washout. A closer look at the ring resistivity shows substantial fluctuations with A40L almost acting as its baseline curve. The fluctuations can be interpreted to indicate that the sandy interval is

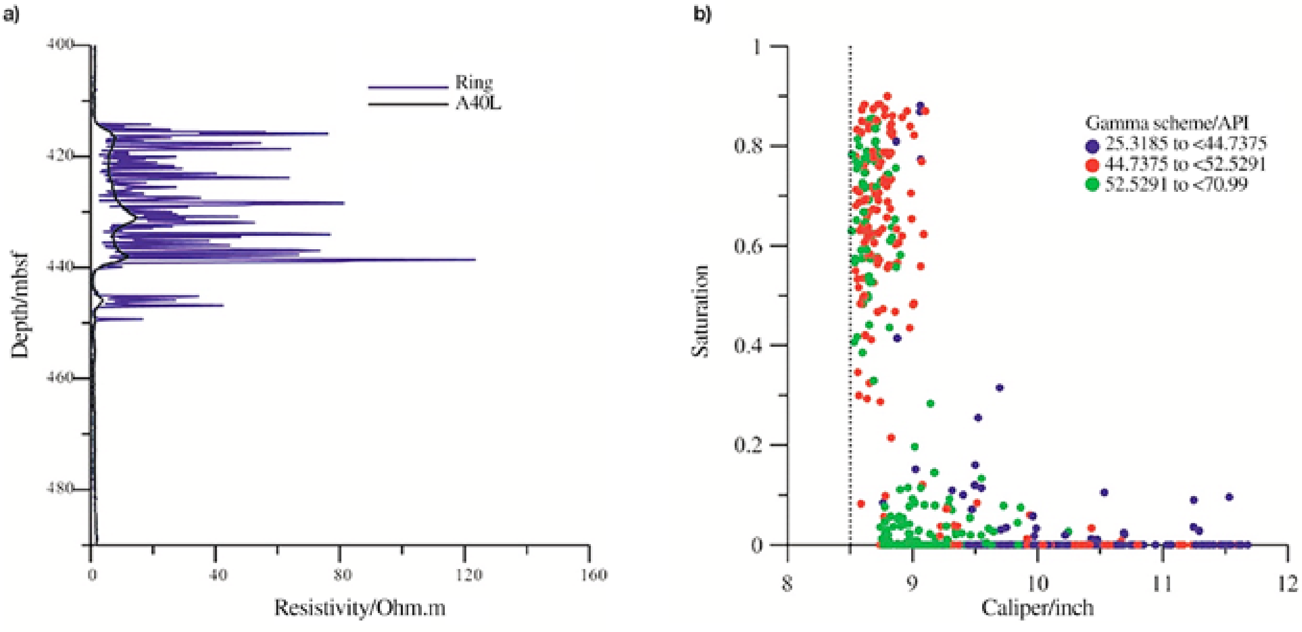

Figure 2. Data analysis. a) Comparison of ring and A40L resistivity, b) comparison of gamma ray and caliper data. While (a) suggests a layered medium, (b) suggests sand-rich, hydrate-free layers are more likely to be mechanically weak.

highly laminated. However, at this stage, we are only presenting saturations at a gross scale averaged over three key intervals (Table 1). Although we present one saturation value for each of the three intervals by averaging the corresponding resistivity and sonic measurements, we acknowledge that it is very likely that these intervals are thinly laminated.

We begin our resistivity modeling using Archie's law, which is a method for interpreting resistivity data while ignoring the intricacies of grain arrangements. For both ring and A40L resistivity, we use, $S_h = 1-(aR_w/\phi^m R_t)^{1/n}$, where S_h is the hydrate saturation, R_t is the measured resistivity, n is an empirical exponent (n=2 in this case), R_w is the resistivity of pore water, a and m are Archie constants (0.9 and 2.2, respectively), and ϕ is the porosity. As expected, in the washed-out units, ϕ, computed from bulk density assuming a limestone base, is highly overestimated. Lee and Collett (2012) showed that washed-out porosities can be replaced by sand-clay model-based porosities proposed by Kolterman and Gorelick (1995) (red line; Figure 1c). The computed saturations for the three key intervals are presented in Table 1.

Interval (mbsf)	Ring Resistivity	A40L Resistivity	Isotropic, cement	Isotropic, load bearing	Laminar
413.5 – 440.5	66.2	56.8	12.2	60.2	67.5
445 – 447	47.8	27.8	6.7	40.2	47.1
449.5	47.6	4.7	5.4	42.3	46.5

Table 1: Hydrate saturation from different resistivity and sonic velocity scenarios.

Finally, we examine compressional wave transit times which were measured using both *SonicVision* and *SonicScope* tools. Velocities computed from the *SonicVision* transit times were consistently ~3% less than velocities computed from *SonicScope* transit times. Based on synthetic seismograms for water-saturated sediments, Lee and Collett (2012) suggested that *SonicScope* velocities better represent *in-situ* physical properties, and are therefore used in this application.

Standard morphologies for a coarse-grained medium (i.e., pore-filling, grain displacing, and cementing) and their effects on sonic velocities are well known. However, those effects assume homogeneous hydrate distribution. For a laminar form, the transverse isotropic (TI) conceptualization of a hydrate-bearing medium, proposed by Lee and Collett (2009), is appropriate. Although the Lee and Collett TI model was originally meant to account for a fractured hydrate-bearing reservoir, the concept can be extended to any form of lamination. This model merges two isotropic end members, one water-saturated and the other hydrate-saturated matrix, into an anisotropic medium. In context of the GC955 reservoir, we use this model to conceptualize a layered arrangement of water-filled and hydrate-filled horizontal sandy units. If n_1 and n_2 are the volume fractions of the end-members, respectively, an elastic constant of the composite media, G, can be expressed as $\langle G \rangle \equiv (\nu_1 G_1 + \nu_2 G_2)$ and $\langle G^{-1} \rangle \equiv (\eta_1 / G_1 + \eta_2 / G_2)$. Corresponding expressions of velocities can be found in the original reference.

Like resistivity, we have averaged the sonic data within individual intervals. Assuming the background to be 80%–20% quartz-clay mixture, saturation provided by the SonicScope data for the cementing and load-bearing morphologies under isotropic condition and laminated condition in the three key hydrate bearing intervals is listed in Table 2. From Table 2, it appears that saturation from both load-bearing isotropic and laminar conceptualizations of the coarse-grained sandy interval compare well with saturation from ring resistivity. Ongoing research attempts to better understand hydrate distribution, and to test the Boswell et al. (2012) model of hydrate-bearing sands interbedded with hydrate-free clay. We will approach this by modeling the sonic and resistivity logs at a finer scale and exploring a range of background-sediment compositions, ranging from pure clay to pure quartz, to find a best-fit to the sonic data.

Sources and Suggested Reading

Boswell, R., et al., 2012. Subsurface gas hydrates in the Northern Gulf of Mexico. Journal of Marine and Petroleum Geology, 34 (1), pp. 4-30.

Collett, T.S., et al., 2012. Gulf of Mexico gas hydrate joint industry project Leg II logging-while-drilling data acquisition and analysis. Journal of Marine and Petroleum Geology, 34 (1), pp. 41-61.

Cook, A., et al., 2012. Electrical anisotropy of gas hydrate-bearing sand reservoirs in the Gulf of Mexico. Journal of Marine and Petroleum Geology, 34 (1), pp. 72-84.

Lee, M.W., and Collett, T.S., 2009. Gas hydrate saturations estimated from fractured reservoir at Site NGHP-01-10, Krishna-Godavari Basin, India. Journal of Geophysical Research: Solid Earth (1978–2012), 114 (B7).

Lee, M.W., and Collett, T.S., 2012. Pore- and fracture-filling gas hydrate reservoirs in the Gulf of Mexico gas hydrate Joint Industry Project leg II Green Canyon 955 H well. Marine and Petroleum Geology, 34(1), pp. 62-71.

NETL Methane Hydrate Fellowship Program

The National Academies of Sciences, Engineering, and Medicine, in association with the U.S. Department of Energy's National Energy Technology Laboratory (NETL), administer a Research Fellowship Program designed to support the development of methane hydrate science and enable highly qualified graduate and postgraduate students to pursue advanced degrees and training in an area of increasing national interest.

M.S., Ph.D., and Postdoctoral applicants, who are U.S. citizens and are affiliated with any federal laboratory or accredited university, are eligible for these fellowships. The fellowships are two or three years in duration.

The NETL-NAS Methane Hydrate Fellowship holds semi-annual application reviews. Two open periods for applications are available to interested individuals: 1) December 1-February 1; and 2) June 1-August 1. Instructions for application can be found online at http://sites.nationalacademies.org/PGA/RAP/PGA_050408

Stipends range from $30,000 to $60,000 per year with adjustments for experience. There are also supplements for research equipment and travel.

Contact Dr. Richard Baker, (304) 285-4714, richard.baker@netl.doe.gov or Dr. Ray Boswell, (304) 285-4541, ray.boswell@netl.doe.gov with questions.

DOE Announces $3.8 Million in New Methane Gas Hydrate Research

The U.S. Department of Energy (DOE) has announced the selection of six multi-year research projects to receive $3.8 million in funding that will help to determine the production viability of a vast source of natural gas and assess the role of gas hydrate in the larger global climate cycle. The six new projects will be managed by the DOE Office of Fossil Energy's National Energy Technology Laboratory (NETL).

The University of Rochester (Rochester, NY) will advance understanding of the environmental implications that methane leaking from dissociating gas hydrates could have on the ocean-atmosphere system.

The University of Texas at Austin will conduct a laboratory evaluation of the dynamic petrophysical attributes of gas hydrate–bearing sands in response to pressure reduction at macro- and micro-scale. This research will enhance understanding of hydrate system behavior, improve the ability to simulate hydrate production, and make more realistic estimates of the ability of the hydrate resource to be a viable energy source.

Louisiana State University (Baton Rouge, LA) will conduct a laboratory evaluation of the migration of fine-grained particles during gas production, with specific focus on factors unique to gas production from hydrate-bearing sediments.

Texas A&M University (College Station, TX) will leverage prior NETL research and its own fieldwork data to study the fate of methane in water columns where hydrate shells form around methane bubbles in a process called hydrate bubble armoring.

The University of California at San Diego (Scripps Institution of Oceanography) will assess controlled source electromagnetic (CSEM) technologies for locating marine hydrate deposits. Research will provide a fundamental understanding of the electrical properties of hydrate-bearing sediments and assess the usefulness of CSEM as a complementary technology for locating and characterizing gas hydrates.

Texas A&M University (College Station, TX) will advance the capabilities of a leading integrated model for hydrate system behavior.

LBNL Workshops Held to Assess Data Needs and Modeling Capabilities for Future Gas Hydrate Resource Evaluation

Over the past few years, the international gas hydrate community has completed several large-scale gas hydrate reservoir characterization and production field programs, and it has begun planning longer-term reservoir testing. The combination of newly collected field data and near-term plans for additional site characterization and production testing motivated scientists to convene a pair of workshops to bring together researchers from modeling, field, and laboratory specialties to 1) further our understanding of how to model the coupled thermal, hydrological, and geomechanical processes involved with extracting methane from hydrate *in situ*; and 2) guide advances in downhole or core-based measurements toward the highest priority parameters required for modeling the long term evolution of gas hydrate reservoirs during production.

The workshops were hosted by Lawrence Berkeley National Laboratory. They were held on December 11, 2016, one day prior to American Geophysical Union Fall Meeting to take advantage of international attendance at the conference. The workshops drew participation from 26 researchers, including scientists and engineers from the US, Canada, UK, Japan, and South Korea.

The morning workshop focused on planning the 2nd International Code Comparison project, for modeling a series of hydrate reservoir problems of increasing complexity. The afternoon workshop focused on measurement parameters and built on morning discussions about critical reservoir modeling needs. It also addressed participants' concerns and insights related to existing data, data gaps, and measurement opportunities. Both workshops represent initial steps toward ongoing collaborations open to the international gas hydrate community. Researchers interested in participating may contact workshop organizers:

Dr. Timothy Kneafsey (LBNL): TJKneafsey@lbl.gov
Dr. Yongkoo Seol (NETL): Yongkoo.Seol@NETL.DOE.GOV
Professor Sheng Dai (GaTech): sheng.dai@ce.gatech.edu
Dr. William Waite (USGS): wwaite@usgs.gov

Ninth ICGH to be held June 25-30, 2017 in Denver, Colorado

The ninth ICGH conference in a series stretching back to 1993, will be held next summer in Colorado. Attendance at the ICGH has grown, and 2017 should be no exception. The conference aims to bring together the entire gas hydrate community, to review developments over the previous three years, and to attempt to extrapolate for the near-term future. Topics include gas hydrate fundamentals, exploration of natural gas hydrates, applied flow assurance, energy recovery from natural hydrates, climate change, and gas hydrate-related geohazards.

For more information, including deadlines, visit http://icgh9.csmspace.com/

Spotlight on Research

JÜRGEN MIENERT

The Arctic University of Norway

Jürgen Mienert's interests as a scientist cross the line between earth and sea, so it is not surprising that his introduction to geology began at the seashore. Growing up in northern Germany meant school trips to the North and Baltic Sea coasts, where he became fascinated with rocks dropped by ice age glaciers and the chalk beds with fossils for collecting.

After military service with the air force he flirted with the notion of studying astrophysics but came back to earth, landing in Kiel and receiving his diploma in geology at the university there. After time as an exploration geologist with Texaco in the North Sea, he traveled to the States to study at Lamont-Doherty Geological Observatory at Columbia University, with Dr. Marcus Langseth.

Jürgen returned to The University of Kiel to focus on marine geology, spending many months on research vessels, such as the RV *Meteor* ("old white lady"), *Valdivia, Poseidon*, and icebreaker RV *Polarstern*, studying seismic reflection events in subsea sediments beneath the ocean floor.

With his PhD in geosciences, he re-crossed the Atlantic for a post-doc at Woods Hole, doing geomarine acoustic stratigraphic research and collecting new data aboard the RV *Knorr* and the *JOIDES Resolution* on ODP Legs 108 and 114. He then returned to Kiel to join other researchers at the newly established GEOMAR, Center for Marine Geosciences at the Christian-Albrechts-University. There, Mienert built a team of marine geophysicists to work on oceanic gas hydrate dynamics. Expeditions included the Norwegian Ormen Lange deep-water gas field investigations, diving with the submersibles MIR to ocean floor gas hydrate and gas release sites located at Storegga on the Mid-Norwegian Margin, and studying the Haakon Mosby Mud volcano on the Barents Sea Margin.

Since 1998, Mienert has been Professor for Applied Geophysics and Arctic Marine Geology at The Arctic University of Norway in Tromsø, Norway, where he is Director of the Centre for Arctic Gas Hydrate, Environment and Climate (CAGE). Mienert has also spent time as a visiting scientist at both Scripps Institution of Oceanography and IFREMER.

His current work focuses on understanding the rate at which rising ocean temperatures may destabilize shallow, Arctic methane hydrate reservoirs, leading to geohazards, ocean acidification, and marine benthic responses. CAGE collaborates with teams from Russia, USA, Canada, and Europe on research efforts targeting Arctic shelf and slope environments, facilitating active cooperation among hydrocarbon companies, technology providers, and Arctic research groups. According to Jürgen, the Centre's overarching goal is …"*to achieve a quantitative understanding of the feedback between methane sub-seabed reservoirs, the seabed, and the ocean. How this coupled system reacts and affects the future ocean, its environment, and possibly the climate, is of global importance.*"

Beyond his scientific endeavors, Jürgen enjoys cross country skiing, spending time with his grandchildren in England, and reading a wide variety of well known (and not so well known) authors. His eclectic taste in music reflects the range of places he has spent time studying hydrates—he enjoys German and Norwegian jazz, Russian cellists, and blues-inspired rock of Houston's own ZZ Top.