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Fire in the Ice

THE NATIONAL ENERGY TECHNOLOGY LABORATORY METHANE HYDRATE NEWSLETTER

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Marine Multi-Component Seismology in Gas Hydrate Investigations on the Norwegian Margin

by Stefan Bünz[1], Jürgen Mienert[1], Karin Andreassen[1], and Karl A. Berteussen[1,2]

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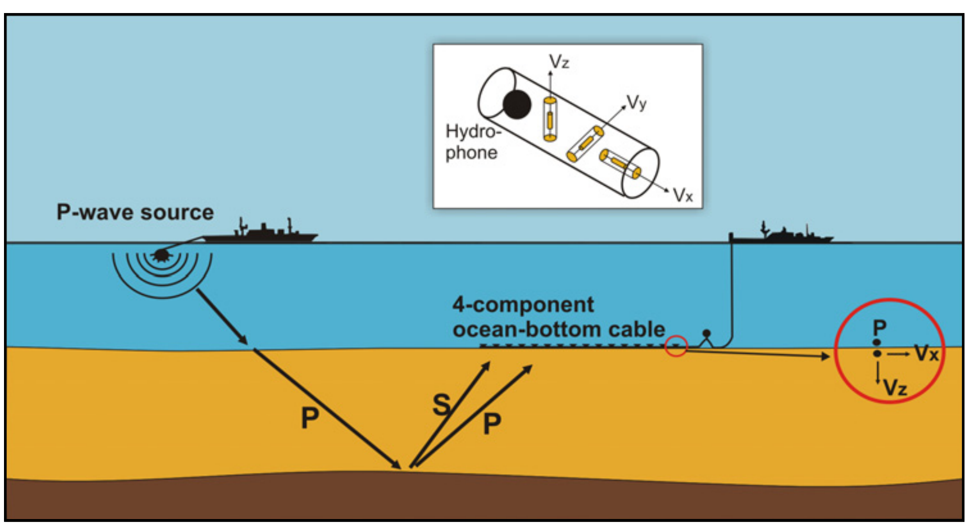
The presence of free gas at the base of the gas hydrate stability zone underneath gas hydrates is typically identified from a characteristic bottom-simulating reflection (BSR) on P-wave seismic data. This reflection, however, provides only very little information about the hydrate-bearing sediments, making a characterization of the micro-scale distribution of gas hydrates using P-wave data alone ambiguous. Work carried out by researchers at the University of Tromsø has shown that the use of multi-component seismic data can permit resolution of the ambiguities that result from the acquisition of P-wave data alone.

Multi-Component Seismology

Marine multi-component seismology has gained attention in recent years due to the development of new acquisition and processing methods. The concept involves placing four-component sensing systems on the seafloor to record the full vector wavefield of reflected energy (see figure). In essence, this means recording both compressional waves (P-waves) and shear waves (S-waves) using sensor packages containing hydrophones and three-component geophones.



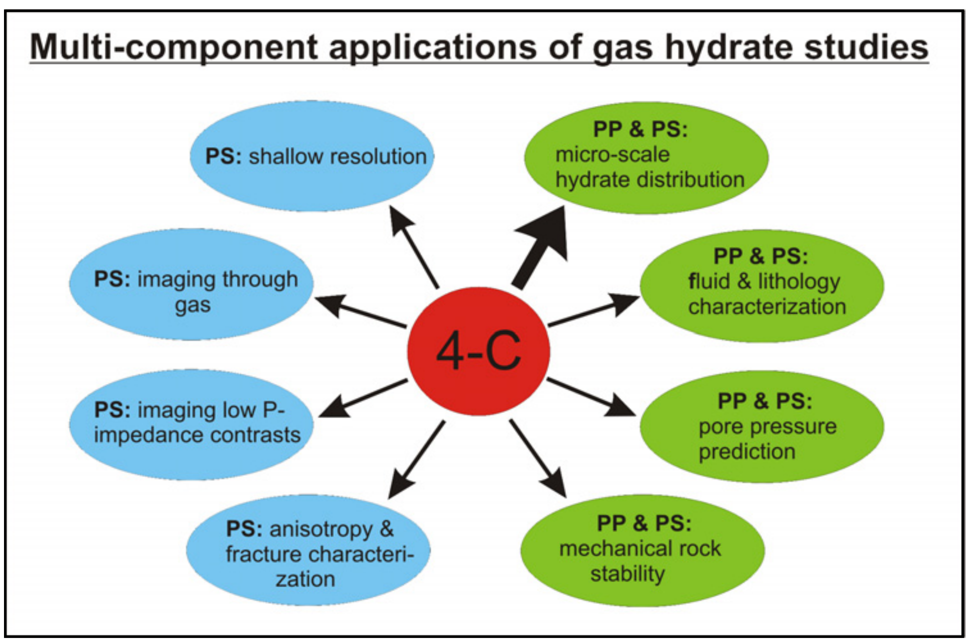
Acquisition principle for marine multi-component seismic data. The rays illustrate how a downgoing P-wave generates an upgoing P-wave, but also converts upon reflection, creating an upgoing S-wave.

Conventional marine-towed streamer systems that are one-component systems, use only hydrophones and therefore record only P-waves. Multi-component systems, while more expensive, also allow recording of S-waves. In the case of marine multi-component seismic data, two ships are often used. One ship deploys the 4-component system while another ship tows a P-wave source. Both P- and S-waves are recorded by sensor packages that include one hydrophone, a vertical geophone and two horizontal geophones oriented perpendicular to each other. All four are included in each receiver group. This approach provides more acoustic information about the properties of rocks and fluids than is obtained by recording only one component. S-waves are generated from P-waves impinging on lithologic boundaries with different rock properties. Such wave types are called converted waves (C-waves) or PS-waves.

A P-wave that propagates through rock is affected by both the rock matrix and the pore fluids. When an S-wave passes through rock, its behavior is affected mainly by the matrix of the rock and only to a very minor degree by the pore fluids. Another important property of S-waves is that they are much slower than P-waves (up to 8 – 10 times slower in the shallow subsurface). Combining information from S-waves with that obtained from P-waves gives a much more complete interpretation of a reservoir.

Application of Multi-Component Seismology to Hydrates

Imaging through gas-obscured areas and increased resolution are likely to be the primary benefits of multi-component applications. The primary potential of S-wave information in the investigation of gas hydrate-bearing sediments lies in the combination of two factors: (1) the high S-wave velocity of pure methane hydrate (~1900 m/s) compared with the typical low S-wave velocity of deep marine hydrate-free sediments (100 – 600 m/s) and (2) the fact that S-waves are hardly affected by free gas that underlies the hydrate-bearing sediments. S-waves, therefore, may be directly related to gas hydrate concentrations.



The range of multi-component applications that promote the understanding of gas hydrate systems. In blue are all the ones based on converted (PS) waves. In green are all the applications involving both the PP and the PS mode. The thick arrow highlights the prime application of multi-component technology in gas hydrate studies.

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INTENT

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.

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

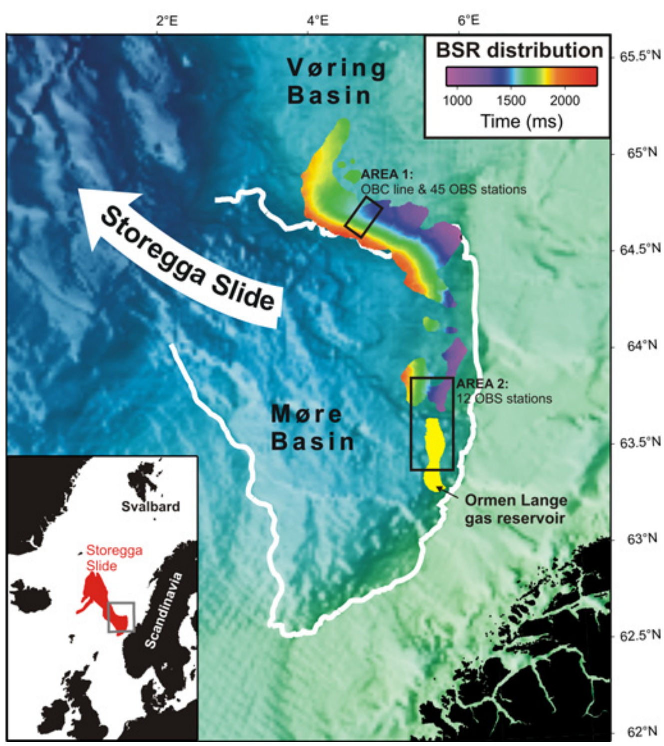
This newsletter now reaches nearly 500 scientists and other individuals interested in hydrates in sixteen countries. If you would like to submit an article about the progress of your methane hydrates research project, please contact Karl Lang at 301-354-2033 (klang@hartenergy.com)

The primary application of multi-component data in hydrate studies is to resolve the micro-scale distribution of gas hydrates within sediments, that is, to determine if hydrates are disseminated within the pore space or if the hydrates cement grain contacts (see figure). The presence of cementing hydrates would increase the rigidity of the sediments, which in turn would lead to an increase in S-wave velocity. Furthermore, S-waves provide a much clearer image of sediment stratigraphy and subsurface structure as they are unaffected by the presence of gas that occurs underneath the hydrate-bearing sediments and thus offer a much better seismic resolution. Other useful applications in hydrate settings involve imaging of low P-wave impedance contrasts, anisotropy and fracture characterization, fluid and lithology characterization, pore pressure prediction and mechanical rock analysis. These last two applications are important as gas hydrates are a known drilling hazard and widely considered to be involved in slope instabilities.

Multi-Component Investigation of Hydrates on Norwegian Margin

Throughout the last six years the Department of Geology of the University of Tromsø has spent substantial amounts of time investigating the gas hydrates on the Norwegian Margin using multi-component seismic data. Much of this has been fostered by the fact that Petroleum Geo-Services, Oslo, has acquired a 4-km long multi-component ocean-bottom cable (OBC) seismic line in an area with hydrate-bearing sediments (see figure). That OBC line was subsequently made available to our group at the University of Tromsø. In addition to the OBC line, we have acquired data from up to 100 ocean-bottom seismometer (OBS) stations at locations where conventional P-wave seismic data provided evidence for the presence of gas hydrates or free gas within the sediments.

The OBC line was the first ever acquired over a gas hydrate-related BSR. The seismic data are of very good quality, and display strong P-S converted wave reflections for the whole sediment column (see figure). S-wave reflections mainly result from stratigraphic boundaries, where an S-wave impedance contrast exists, and thus the mode-converted waves yield direct and more accurate information about the shear properties of the subsurface. Due to the fact that

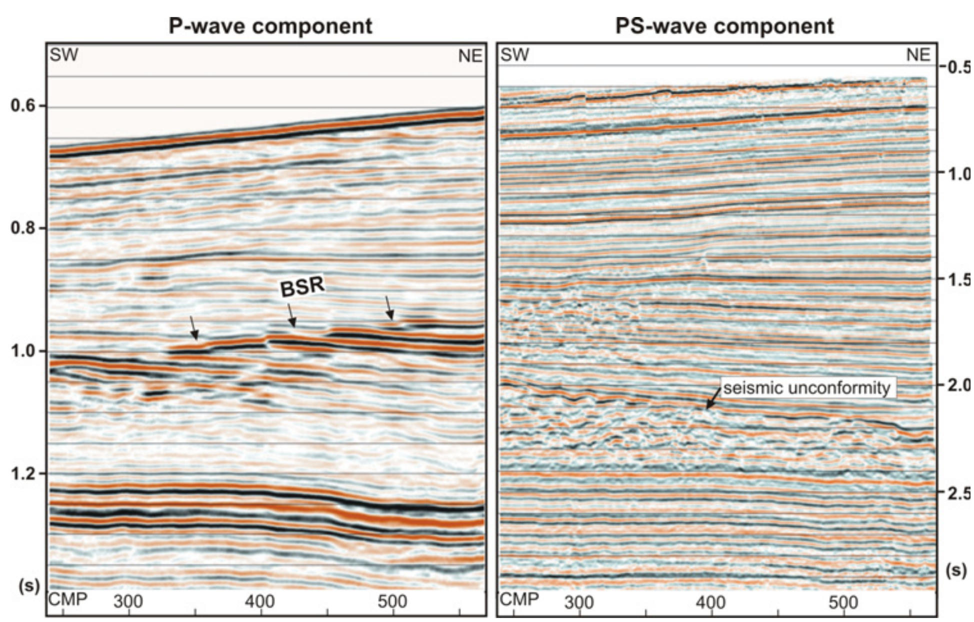


Map showing the distribution of the BSR on the mid-Norwegian margin and the coverage of multi-component data in this area. In addition, there are about 40 OBS stations on the western Svalbard margin.

the S-wave velocity is much lower than the P wave velocity, the seismic resolution increases and the inline component of the OBC survey provides a much more detailed image of the subsurface. Improved acoustic images allow us to look through the zone underneath the hydrate-bearing sediments, which is obscured on the P-wave data due to the occurrence of gas.

The P-wave component shows a clear BSR about 350 ms underneath the seafloor reflection. No P-S reflections are associated with the BSR along this line, indicating that the gas hydrate-bearing sediments at the base of the hydrate stability zone are not stiff enough to increase the shear modulus of the sediments to produce P-S converted wave reflections. The observations on both P-wave and PS-wave components of the OBC line favor a model in which gas hydrates are disseminated within the pore space. This is corroborated by P- and S-wave velocities derived from OBS data from the same area. The multi-component data has further allowed us to resolve ambiguities that would exist using the P-wave data alone. For example, above the Ormen Lange deep-water gas reservoir, OBS data is able to provide an unambiguous interpretation of the subsurface structure, thereby distinguishing between lithologic effects and the effects that occur in the presence of gas hydrates or free gas.

At the moment, our main effort is directed towards understanding the dynamics of the free gas system. To this end we are assessing the pore pressure distribution within the hydrate/free-gas system using the OBC line. Moreover, in cooperation with a group from the Istituto Nazionale di Oceanografia e di Geofisica Sperimentale (OGS), in Trieste, Italy, we are applying tomographic traveltime inversion to an array of data from 21 OBSs to obtain a three-dimensional velocity volume. This volume will be integrated with three-dimensional seismic interpretation, which will allow us to investigate the relationship between subsurface fluid conduits and the free gas zone underneath the hydrates. It is aimed towards improving our understanding of the interaction of gas-laden fluids with the subsurface structure, and the hydrate and gas accumulation mechanisms.



Stacked sections of P-wave and the PS-wave component of the OBC line, which has a length of approximately 4 km. Note the difference in time axis. The inline component has been linearly stretched in time to match the P wave data based on a horizon, which occurs just below a sedimentary layer with chaotic internal texture labeled "seismic unconformity."

SUGGESTED READING

Bünz, S., J. Mienert, and C. Berndt, Geological controls on the Storegga gas-hydrate system of the mid-Norwegian continental margin, Earth Planet. Sci. Lett., 209, 291–307, 2003.

Andreassen, K., K. A. Berteussen, H. Sognnes, K. Henneberg, J. Langhammer, and J. Mienert, Multicomponent ocean bottom cable data in gas hydrate investigation offshore of Norway, J. Geophys. Res., 108(B8), 2399, 2003.

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Mienert, J., S. Bünz, S. Guidard, M. Vanneste, C. Berndt, Ocean-bottom seismometer investigations in the Ormen Lange area offshore Mid- Norway provide evidence for shallow gas layers in subsurface sediments, Mar. Petr. Geol., in press.

Discovery of Possible Gas Hydrate Features Offshore Norway

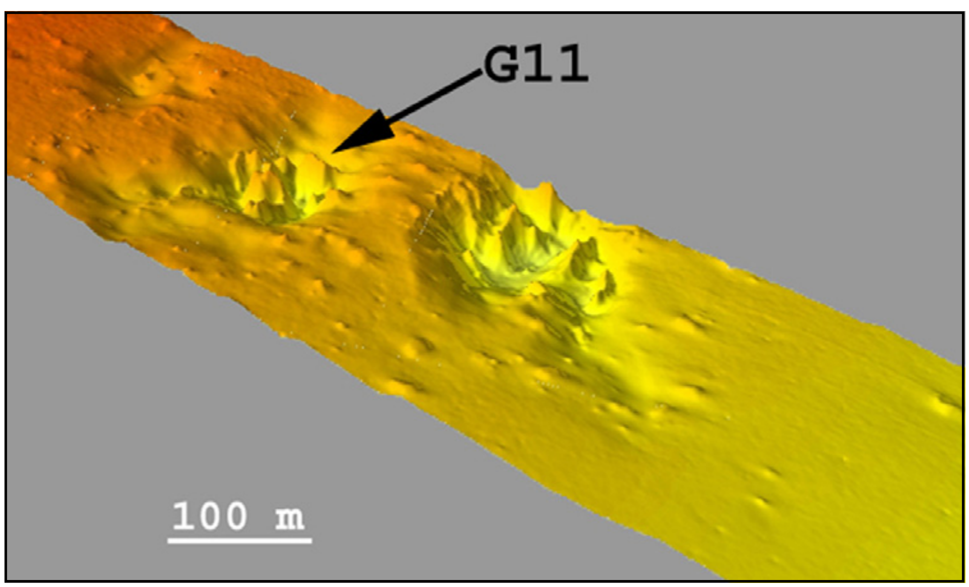
by Martin Hovland, Statoil, Stavanger, Norway

A detailed seabed survey carried out in March 2003 at the Nyegga region of the continental slope off the coast of Norway discovered a rugged seafloor terrain that included a large complex of pockmarks with thick internal piles of carbonate rocks and soft, fluid-generating pingo-like structures suspected of containing gas hydrates.

The Nyegga region is located at a water depth of about 750 m on the northern flank of the well-known Storegga submarine slide, which occurred about 7200 years ago. In this region, bottom-simulating reflectors (BSRs) are well known features, together with pockmarks and suspected mud diapirs first reported over 20 years ago. Statoil conducted two surveys in the Nyegga region and has discovered evidence of locally dynamic sediments, much like those found in terrestrial freeze/thaw locations.

The rugged features known as "complex pockmarks" can be seen on an image produced by multibeam echosounding carried out from the ROV *Hirov* deployed from the survey vessel Normand Tonjer (see figure). Photos taken by that *Hirov* inside the G11 complex pockmark show large carbonate rocks that are suspected to have formed sub-surface and subsequently been pushed upwards, either by freeze-thaw processes or by the expulsion of gas.

A close-up of the seabed near one of these large carbonate blocks reveals a conical mound that appears to be a pingo-like structure (see photos). Commonly found in Arctic permafrost regions, a pingo is a geological feature caused by hydrostatic pressure that develops as underground ice expands. The features observed offshore Norway are covered by carpets of small tubeworms. The white blotches are mats of bacteria that grow where water and gas seep out of the ground, possibly above dissociating hydrate or melting ice inside the mound.

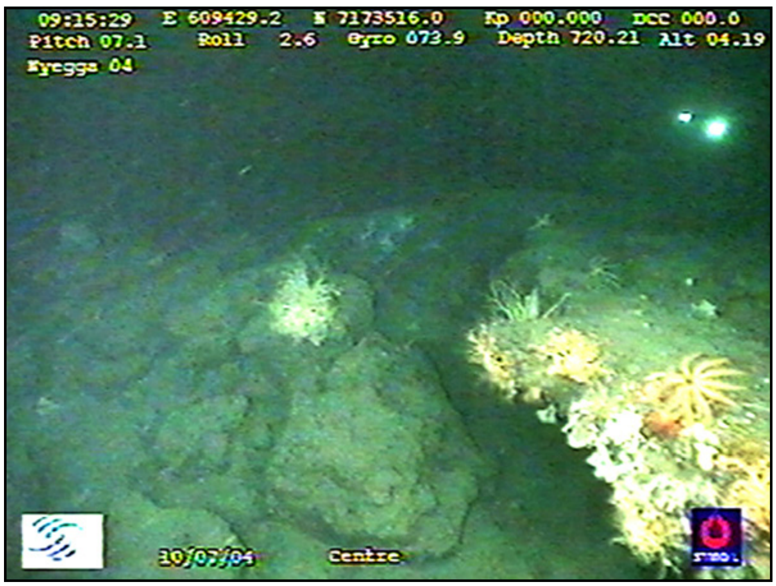


Echosound image of the Nyegga site with vertical scale enhanced by a factor of three. The pockmark named "G11" has a diameter of about 150 m and is the primary study location.

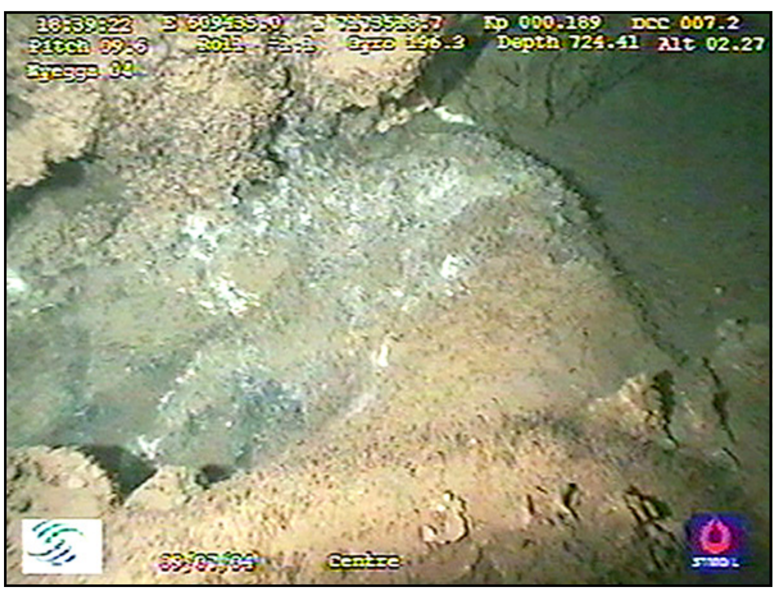
The physical processes at work here are thought to include continuous migration of methane gas from deeper sediments, the formation of ice or hydrate in the near subsurface, the melting and subsequent release of fresh water and dissolved gases, nourishment to primary producers (the bacteria) by this release, and the growth of filter-feeders and other free-swimming microorganisms that utilize the nutrients produced by the bacteria (tubeworms, sea anemones).

A second pingo-like structure, also found at the G11 pockmark crater, is about 3 meters wide and 1 meter high. A close-up of this mound reveals the characteristic carpet of small tube-worms, and a pit in the surface where subsurface ice is actively melting, and sediment grains are transported away by the melt-fluids. A third pingo-like structure was also photographed during the dive in the G11 complex pockmark at Nyegga.

These images provide just a few examples of the variety of geological structures that can be created under the dynamic conditions surrounding natural gas and fresh water flux at deepwater seabed locations. If you have opinions, questions, or insights about the interpretations of the features observed at Nyegga, please contact the author at: mhovland@statoil.com.

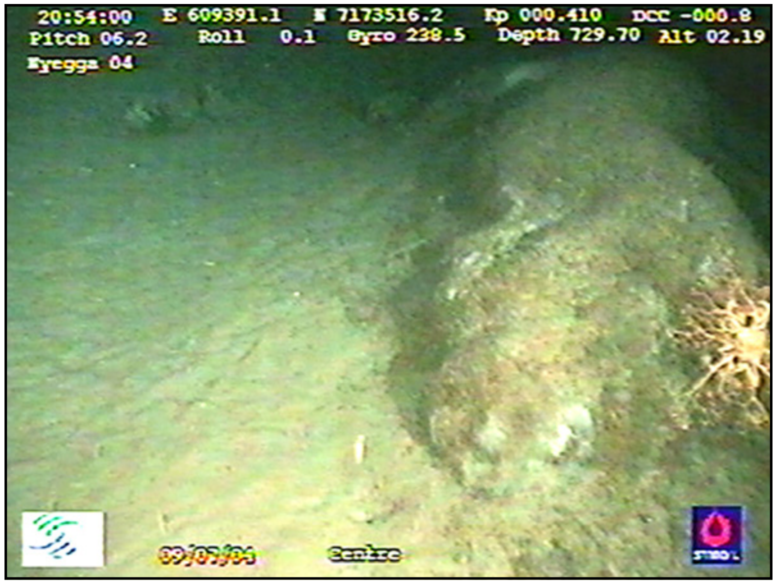


ROV photo taken inside the G11 complex pockmark showing terrain with large carbonate rocks (lights at upper right from second ROV at 15 m distance).

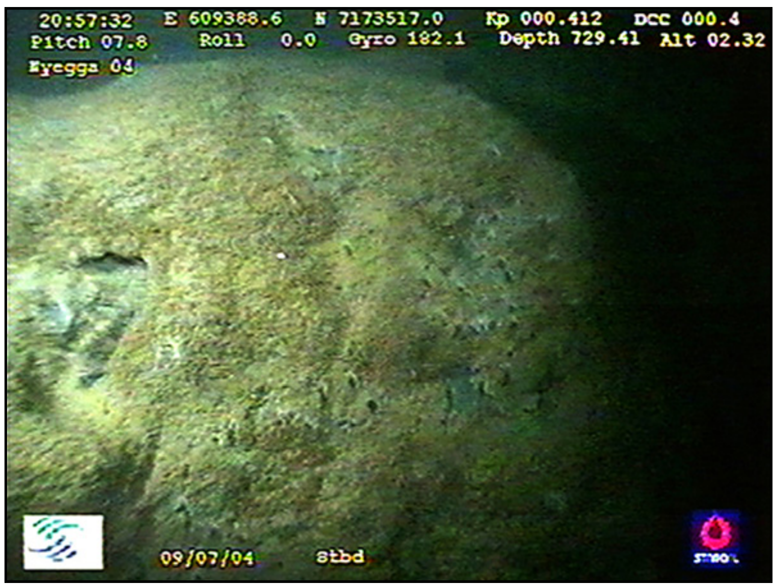


Pingo-like structure with covering of bacteria and tube worms.

Second example of pingo-like feature found at G11 pockmark.



Close up showing "corrosion" of pingo-like feature with melting of subsurface ice.



Third pingo-like feature photographed at the same G11-location.

MISSISSIPPI CANYON BLOCK 118 SEAFLOOR-MONITORING STATION UPDATE

by Carol Lutken, Center for Marine Resources and Environmental Technology at the University of Mississippi

The first of three cruises scheduled for this year in support of the Mississippi Canyon 118 seafloor-monitoring station project took place May 15-19 aboard the *R/V Pelican.* Two 10m long sensor arrays were deployed *via* a gravity-driven Sea Floor Probe system. In addition to the deployments, 3m and 10m core samples were recovered. The probes will provide the shallow downhole component of the monitoring station until deep boreholes can be constructed to accommodate longer (100 to 200m) arrays. One of the two is a Pore-Fluid Array (PFA) designed to collect pore-fluid samples continuously from four different depths in the shallow, near-seabed hydrate stability zone. The second is a thermistor Geophysical Line Array (GLA), an array of temperature sensors, designed to complement the PFA and to provide input into the investigation of the extent of the gas hydrate stability zone. Although the prototype GLA contains only thermistors, geophones and other geophysical sensors will be included on a future version of the geophysical array. Both arrays are designed to be serviced by small remote vehicles. The core samples collected will provide much-needed geological and geochemical information as well as depositional history for the area.

Laura Lapham (University of North Carolina) making the final predeployment check of the osmopumps, key components of the PFA

Jim Gambony and Paul Higley (kneeling) of SDI, Inc. and Bob Woolsey, Director of CMRET and the Consortium, with the GLA, prior to deployment.

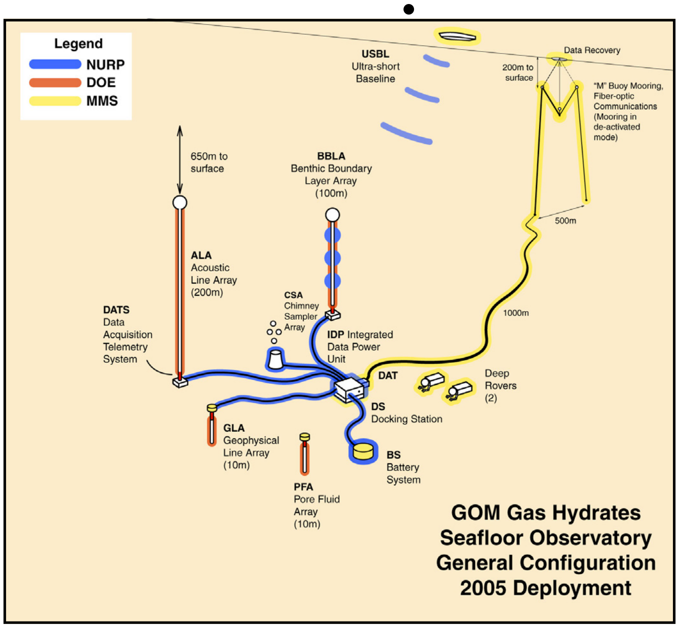
Deployment of the Pore-Fluid Array (PFA)

Additional cruises during September-October 2005 will be focused on surveying the seafloor to determine precisely where additional components of the monitoring station should be located. In addition, we will deploy additional sensor systems, connect components, run a seismic survey to test the data retrieval system, and collect and replace sample coils on the geochemical probe deployed in May.

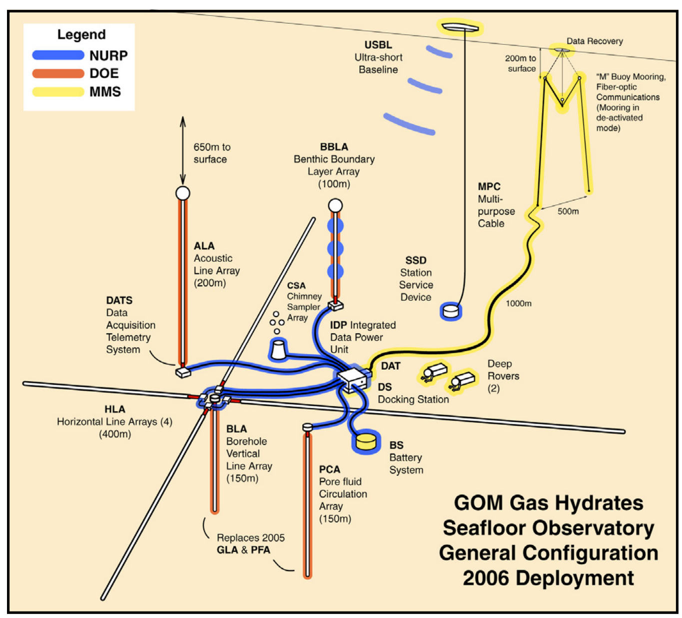
Deployment of additional elements will be carried out during 2006. The Station has evolved since its original conception, primarily in response to changing circumstances and advances in technology. The geophysical sensor system concept now calls for a single water-column acoustic line array (ALA) located in close proximity to four horizontal arrays (HLAs) laid out in a cross pattern on the seabed (see figures). Plans include gaining access to one or more boreholes for the installation of at least one borehole vertical line array (BLA), as well as alternative concepts for geophysical sensing. Geochemical sensors include components to be suspended in the water column, as well as those on the sea floor in the subsurface. A number of Station Support Systems (SSS) continue to be developed for the installation, operation, and maintenance of the station.

The seafloor monitoring station is being developed by the Center for Marine Resources and Environmental Technology (CMRET) at the University of Mississippi through the Gulf of Mexico Hydrates Research Consortium. The Consortium is comprised of researchers from around the world and includes university, industry and government participants. Support for the project is provided by the Minerals Management Services (DOI-MMS), the National Energy Technology Laboratory (DOE-NETL), and the National Institute for Undersea Science and Technology (NOAA-NIUST). The elements of the station that are designed to be deployed during 2005 and 2006, are shown in the graphics included here and identified according to the sponsoring organization.

For a more complete description of the goals and purpose of the observatory, please refer to the article published in the Summer 2004 issue of *Fire in the Ice* available online at http://www.netl.doe.gov/scngo/NaturalGas/hydrates/index.html/.



GOM Gas Hydrates
Seafloor Observatory
General Configuration
2005 Deployment



GOM Gas Hydrates
Seafloor Observatory
General Configuration
2006 Deployment

Announcements

Example of the transfer of a hydraulic piston core into the core processing van

A pressure core on ice awaiting transfer to the van.

Research Cruise Completed in the Gulf of Mexico

Between April 17 and May 21 the semi-submersible drilling vessel *Uncle John* carried out a 35-day research voyage for the ChevronTexaco Gulf of Mexico hydrates joint industry project (JIP). During the expedition, researchers collected drilling, logging, and coring data from wells drilled at locations in the Keathley Canyon and Atwater Valley blocks, to characterize methane hydrates in the deepwater Gulf.

A total of four wells were drilled at the Atwater Valley Blocks 13 and 14. The first two wells were logged-while-drilling and coring operations were carried out at the second two locations. One of these two was successfully logged as well. Three wells were drilled at Keathley Canyon: two were evaluated with logging-while-drilling and a third via coring. Surface push cores and a variety of other data were collected at both sites.

A special section of the SCNGO website provided background project information, scientific objectives, status reports, scientific updates, and pictures as they were made available. The direct link to the NETL-JIP Cruise website is: http://www.netl.doe.gov/scngo/NaturalGas/hydrates/index.html/.

All coring and logging activities were concluded and the Uncle John has returned safely to port. Post-cruise analysis of the cores and logs is underway. As results are obtained they will be posted on the National Methane Hydrate R&D Program website.

Advisory Committee Meeting

On June 7-8, the Methane Hydrate Advisory Committee, a 10 member advisory committee to the Secretary of Energy, met in Galveston, TX. Topics for discussion included: research updates (especially the Joint Industry Project Gulf of Mexico drilling), future program directions, and changes in advisory committee structure. DOE also hosted a meeting of the Interagency Coordinating Committee concurrent with the first morning of the Advisory Committee meeting. Jim Slutz, DAS for Oil and Natural Gas, was named the Designated Federal Official for this meeting. Besides Advisory Committee members, attendees included DOE program managers and industry representatives. Interagency Coordinating Committee participants included representatives from the National Oceanic and Atmospheric Administration, Naval Research Lab, U.S. Geological Survey, Minerals Management Service, National Science Foundation, and the Department of State.

Hot Ice Project Reports Available

Five topical reports and the final report from the Hot Ice project are now available in the National Methane Hydrate R&D Program Library on the NETL website. Go to http://www.netl.doe.gov/scngo/NaturalGas/hydrates/index.html, click on “Methane Hydrate Library,” then “Publications,” then “Project Reports” from the choices on the right. The Hot Ice project was a cost-shared effort between DOE, Maurer Technology Inc., Anadarko Petroleum Corp., and Noble Corp. to develop technology and to drill and test a dedicated hydrate well on the North Slope of Alaska.

Announcements

The Fifth International Conference on Gas Hydrates
June 13 - 16, 2005 - Trondheim - Norway

Norway ICGH Meeting

The Fifth International Conference on Gas Hydrates (ICGH 5) will take place at the Royal Garden Hotel in Trondheim, Norway, on June 13-16. It is expected that more than 300 flow assurance and gas hydrate specialists from around the world will be in attendance to witness 24 oral presentations and 220 poster presentations. The conference is organized around the following five topical sessions: Kinetics and Transport Phenomena; Structure and Physical Properties; Exploration, Resources and Environment; Industrial Applications and; Thermodynamic Aspects. Details and registration are available on the Conference website at http://www.icgh.org/.

Reservoir Simulator Publicly Released

LBNL's hydrate reservoir simulator (TOUGH-Fx/HYDRATE v1.0) is now publicly available for licensing. TOUGH-Fx/HYDRATE models non-isothermal gas release, phase behavior and flow of fluids and heat in complex geologic media. The code can simulate production from natural methane hydrate deposits in permafrost and in deep ocean sediments, as well as laboratory experiments of hydrate dissociation/formation in porous/fractured media. TOUGH-Fx/HYDRATE v1.0 includes both an equilibrium and a kinetic model of hydrate formation and dissociation. For more information about the model and how to obtain a license, please visit http://www.netl.doe.gov/scngo/Natural%20Gas/hydrates/index.html and select "FWP-G308" from the lefthand menu "DOE Projects" list or contact: Seth Rosen, Senior Licensing Associate, Technology Transfer Department, Lawrence Berkeley National Laboratory, Phone (510) 486-4303 or vial e-mail (SBRosen@lbl.gov).

PetraSim V2.4 for TOUGH-Fx/HYDRATE

PetraSim Version 2.4 - is an interactive preprocessor and postprocessor tool to rapidly develop models and view results for TOUGH-Fx/HYDRATE. PetraSim Version 2.4 can be downloaded for a free 30 day trial at: www.petrasim.com. Example input, output, and manual files can be downloaded at: http://www.thunderheadeng.com/petrasim/help/tough/examples.htm . For additional information please contact Thunderhead Engineering at: Thunderhead Engineering Consultants, Inc., 1006 Poyntz Ave., Manhattan, KS 66502-5459, Phone (785) 770-8511 (or via e-mail at sales@thunderheadeng.com).

Committee to Meet During AAPG Convention

During this year's annual AAPG convention in Calgary, a meeting of the Energy Minerals Division's Gas Hydrate Committee has been scheduled for Tuesday evening, June 21, from 5:30 to 8:00 pm at the Hyatt Regency (Imperial Rooms 1 and 2). Several presentations are planned that focus on recent developments in the gas hydrate field. In addition, plans will be made for additional activities by the committee and its members. Individuals interested in attending shuld contact Committee Chair Art Johnson at art_johnson@hydrate-energy.com/.

SCOTT DALLIMORE

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Scott's interest in the Arctic began twenty-six years ago when he skied across Baffin Island with five friends from Queen's University. The five still get together at Rocky Mountain ski resorts, where the chance of meeting polar bears is significantly less.

Arctic Hydrates—an Engineer's Interest

In a methane hydrate research community dominated by geologists, geophysicists and geochemists, it's always worthwhile to hear from the engineers' side of the aisle. Scott Dallimore has found his past work as a geotechnical engineer working on permafrost engineering problems very useful for gas hydrate research; many of the properties of gas hydrates in sediments are similar to those of ice in permafrost. And like most engineers, Scott became hooked on the science while trying to solve a practical problem: how to successfully carry out a Geological Survey of Canada drilling program aimed at collecting deep core samples of permafrost in the Mackenzie Delta. *"The GSC program in 1992 was a collaborative effort with Shell Canada and Imperial Oil. While drilling a hole at the Taglu well site we encountered both free gas and visible gas hydrates within the permafrost itself. We had a very exciting time sorting out the science on the spot,"* recounts Scott. This event led Dallimore and his GSC colleagues to seek out others engaged in Arctic hydrate research in the United States and Russia.

One thing that fascinates Scott about methane hydrates is the fact that much of the work done in the field is new science. *"Every time a new drilling program is conducted we are undertaking frontier exploration research and development."* While most of his expertise and experience has been in the north, Dallimore remains very interested in the progress being made in marine gas hydrates research. *"The scale and intensity of recent Japanese activity in the Nankai Trough is impressive, and the accomplishments of several major ODP gas hydrate studies, such as Legs 164 and 204, are really quite remarkable,"* observes Dalilimore. Scott has a small role in a new IODP Expedition planned for the Cascadia margin this fall, which he hopes will yield yet more exciting new methane hydrate science.

Dallimore feels fortunate to have been able to play a role in a number of large integrated Arctic field programs that approach the IODP expeditions in scope. In designing these programs Scott has tried to incorporate lessons learned from the IODP experience, adapting them to the logistics and technical challenges of the Arctic. He points out the fact that these Arctic programs have taken on the challenge of pursuing both fundamental and applied research goals. *"The Mallik 2002 production research well program has been our most challenging effort to date,"* states Dallimore. *"Beyond the fact that we achieved our objective of collecting the first well-constrained data set on the production response of gas hydrates, I am very proud of the fact that we did it with a multidisciplinary science approach. Our soon-to-be-released scientific results volume includes 62 papers—more than 150 co-authors and almost a thousand pages of text, as well as a comprehensive database."* Scott points out that the Mallik 2002 program was made possible by partners from Japan, USA, Germany, India and Canada, all of whom assumed substantial risks to enable the project to move forward.

Dallimore is optimistic about the future potential of gas production from methane hydrate deposits. *"If we can maintain the pace of research and development that we have seen in the past five years, I fully expect that production of gas hydrates will become a reality in the next 15 to 20 years, possibly sooner. I expect that first production will be from an Arctic region of Alaska, Canada or Russia, where we have identified concentrated gas hydrate deposits lying above deeper conventional oil and gas fields. However, programs such as those underway in Japan and planned for offshore India may surprise us."*

Scott is quick to acknowledge that he owes a great deal to one particular marine geologist who has worked with him over the years on Arctic geology projects: his wife, Dr. Audrey Dallimore.