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GEOLOGIC AND ENGINEERING CONTROLS ON THE PRODUCTION OF PERMAFROST–ASSOCIATED GAS HYDRATE ACCUMULATIONS

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ABSTRACT

In 1995, the U.S. Geological Survey made the first systematic assessment of the in-place natural gas hydrate resources of the United States. That study suggested that the amount of gas in the gas hydrate accumulations of northern Alaska probably exceeds the volume of known conventional gas resources on the North Slope. Researchers have long speculated that gas hydrates could eventually be a commercial resource yet technical and economic hurdles have historically made gas hydrate development a distant goal rather than a near-term possibility. This view began to change over the past five years with the realization that this unconventional resource could be developed in conjunction with conventional gas fields. The most significant development was gas hydrate production testing conducted at the Mallik site in Canada's Mackenzie Delta in 2002. The Mallik 2002 Gas Hydrate Production Research Well Program yielded the first modern, fully integrated field study and production test of a natural gas hydrate accumulation. More recently, BP Exploration (Alaska) Inc. with the U.S. Department of Energy and the U.S. Geological Survey have successfully cored, logged, and tested a gas hydrate accumulation on the North Slope of Alaska know as the Mount Elbert Prospect. The Mallik 2002 project along with the Mount Elbert effort has for the first time allowed the rational assessment of the production response of a gas hydrate accumulation.

Keywords: gas hydrate, gas, Arctic, permafrost, production, resources, coring, logging

INTRODUCTION

Gas hydrates are naturally occurring "ice-like" combinations of natural gas and water that have the potential to provide an immense resource of natural gas from the world's oceans and polar regions. Gas hydrates are known to be widespread in permafrost regions and beneath the sea in sediments of outer continental margins. The amount of natural gas contained in the world's gas hydrate accumulations is enormous, but these estimates are speculative and range over three orders-of-magnitude, from about 2,800 to 8,000,000 trillion cubic meters of gas. Dr. Alexei Milkov recently reported [1] that the volume of gas trapped in global gas hydrate accumulations was actually in the range of 3,000 to 5,000 trillion cubic meters, which is 1/7 to 1/4 of some of the more widely cited estimates. By comparison, conventional natural gas accumulations (reserves and technically recoverable undiscovered resources) for the world are estimated at approximately 440 trillion cubic meters as reported in the "U.S. Geological Survey 2000 World Petroleum Assessment" [2]. Despite the enormous range in reported gas hydrate volumetric estimates, even the lowest reported estimates seem to indicate that gas hydrates are a much greater resource of natural gas than conventional accumulations. However, it is important to note that none of these assessments has predicted how much gas could actually be produced from the world's gas hydrate accumulations. As an energy resource assessment, much more work is needed both to constrain realistic in-place gas hydrate

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volumetric estimates, and to go beyond these estimates to quantify producible volumes of hydrates.

Gas recovery from hydrates is hindered because the gas is in a solid form, and because hydrates commonly occur in hostile Arctic and deep marine environments. As in the case of conventional hydrocarbon production, first recovery of hydrate resources will occur where the gas hydrate is concentrated. Proposed methods of gas recovery from hydrates generally deal with dissociating or "melting" in-situ gas hydrates by heating the reservoir beyond the temperature of hydrate formation, or decreasing the reservoir pressure below hydrate equilibrium. Computer models have been developed to evaluate natural gas production from hydrates by both heating and depressurization. Depressurization is considered to be the most economically promising method for the production of natural gas from gas hydrates. When evaluating production methods, ecological concerns such as catastrophic gas releases or impact on seafloor stability must also be taken into consideration.

Gas hydrates are often compared to coalbed gas resources, which were also considered to be an uneconomic resource in the not too distant past. However, once the resource was geologically understood, the reservoir properties defined, and the production challenges addressed, coalbed gas became an important part of the energy mix. Now, coalbed gas is a viable fuel in its own right and accounts for almost 10% of the natural gas production in the United States. Our experience with the development of other unconventional energy resources clearly shows that the evolution of gas hydrate into a producible source of energy will require a significant and sustained research and development effort.

ARCTIC GAS HYDRATE ACCUMULATIONS

Gas hydrate in onshore arctic environments is typically closely associated with permafrost. It is generally believed that thermal conditions conducive to the formation of permafrost and gas hydrate have persisted in the Arctic since the end of the Pliocene (about 1.88 Ma). Maps of present day permafrost reveal that about 20 percent of the land area of the northern hemisphere is underlain by permafrost (Figure 1A). Geologic studies [3] and thermal modeling of subsea conditions [4] also indicate that permafrost and gas hydrate may exist within the continental shelf of the Arctic Ocean. Subaerial emergence of portions of the Arctic continental shelf to current water depths of 120 m [5] during repeated Pleistocene glaciations, subjected the exposed shelf to temperature conditions favorable to the formation of permafrost and gas hydrate. Thus, it is speculated that "relic" permafrost and gas hydrate may exist on the continental shelf of the Arctic Ocean to present water depths of 120 m. In practical terms, onshore and nearshore gas hydrate can only exist in close association with permafrost, therefore, the map in Figure 1A that depicts the distribution of onshore continuous permafrost and the potential extent of "relic" subsea permafrost also depicts the potential limit of onshore and nearshore gas hydrate.

This paper deals with the assessment of the geologic and engineering factors that control the ultimate resource potential of gas hydrates. This assessment will be conducted mainly through the examination of several relatively well-characterized gas hydrate accumulations in northern Canada, the United States, and Russia (Figure 1B).

Mackenzie Delta, Canada – Mallik Gas Hydrate Accumulation

Assessment of gas hydrate occurrences in the Mackenzie Delta-Beaufort Sea area have been made mainly on the basis of data obtained during the course of hydrocarbon exploration conducted over the past three decades [6]. In addition, three dedicated scientific drilling programs [7] [8] [9] have included the collection of gas-hydrate-bearing core samples. A database presented by Smith and Judge [10] summarizes a series of unpublished consultant studies that investigated well log data from 146 exploration wells in the Mackenzie Delta area. In total, 25 onshore wells (17%) were identified as containing possible or probable gas hydrate. The frequency of gas hydrate occurrence in offshore wells was greater, with possible or probable gas hydrate identified in 36 out of 55 wells (65%).

Prior to the more recently completed Mallik gas hydrate research drilling programs, the most extensively studied gas hydrate occurrences in the Mackenzie Delta-Beaufort Sea region were those

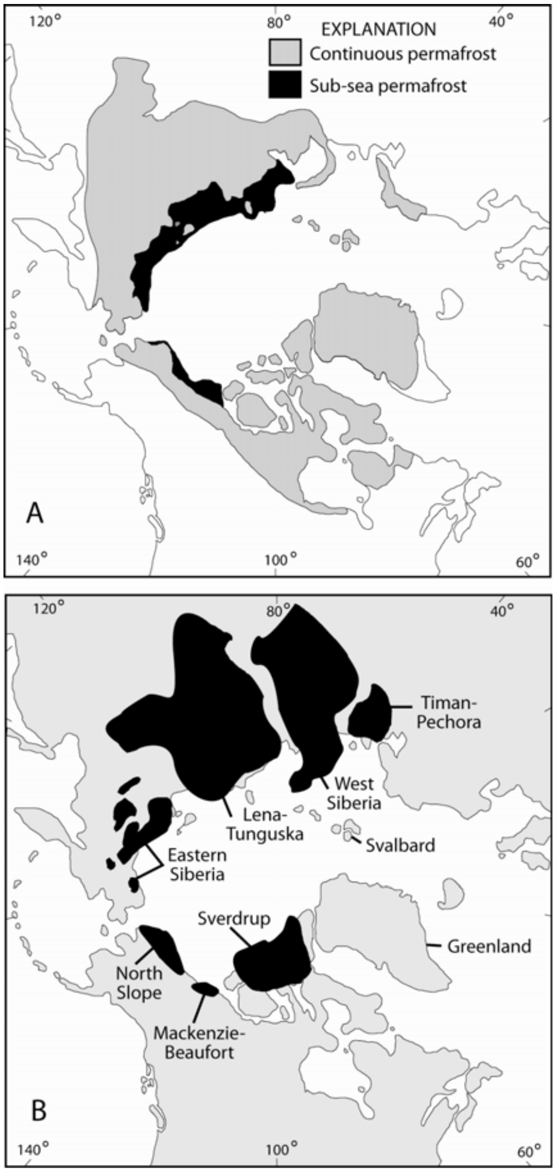

Figure 1. (A) Map of the distribution of permafrost in the Northern Hemisphere [18] and (B) map of sedimentary basins in the Northern Hemisphere that may contain gas hydrates.

drilled in the onshore Mallik L-38 and Ivik J-26 wells [11] and those in the offshore Nerlerk M-98, Koakoak O-22, Ukalerk C-50, and Kopanoar M-13 wells [12]. On the basis of open-hole well log evaluation, it is estimated that Mallik L-38 encountered about 100 m of gas-hydrate-bearing sandstone, and Ivik J-26 penetrated about 25 m of gas hydrate. The well-log inferred gas-hydrate-bearing sandstone units in the Mallik L-38 well occur within the depth interval from 820 to 1,103 m, while in Ivik J-26, gas hydrate occupies a series of fine-grained sandstone and conglomeratic rock units within the depth interval from 980 to 1,020 meters. Analyses of open-hole well logs and mud-gas logs [12], indicate that the offshore Nerlerk M-98 well penetrated about 170 m of gas-hydrate-bearing sediments, while the Koakoak O-22, Ukalerk C-50, and Kopanoar M-13 wells drilled approximately 40 m, 100 m, and 250 m of gas hydrate respectively. In all four cases, the well-log inferred gas hydrate occurs in fine-grained sandstone rock units.

During a permafrost-coring program in the Taglu area on Richards Island in the outer Mackenzie Delta, ice-bearing cores containing visible gas hydrate and possible pore-space gas hydrate were recovered [7]. The visible gas hydrate occurred at a depth of about 330 to 335 m and appeared as thin ice-like layers that released methane upon recovery. Gas yield calculations suggest that other ice-bearing cores from a corehole in the Niglintgak field area on Richards Island also contained non-visible pore-space gas hydrate.

Estimates of the amount of gas in the gas hydrate accumulations of the Mackenzie Delta-Beaufort Sea region vary from 9.3 to 27 trillion cubic meters [13] [14] [15]; however, these estimates are generally poorly constrained. A more detailed study by Osadetz and Chen [16] resulted in an estimate that is within the same bounds given by Majorowiz and Osadetz [15] and range between 1.0 to 10 trillion cubic meters of gas within the permafrost associated gas hydrate accumulations of the Beaufort Sea-Mackenzie Delta region.

The JAPEX/JNOC/GSC Mallik 2L-38 gas hydrate research well, drilled in 1998 near the site of the Mallik L-38 well (Figure 2), included extensive scientific studies designed to investigate the occurrence of in-situ natural gas hydrate in the Mallik field area [8]. Approximately 37 m of core was recovered from the gas hydrate interval (878-944 m) in the Mallik 2L-38 well. Pore-space gas hydrate and several forms of visible gas hydrate were observed in a variety unconsolidated sands and gravels interbedded with non-hydrate bearing silts. The cored and downhole logged gas hydrate occurrences in the Mallik 2L-38 well exhibit both high electrical resistivities and rapid acoustic velocities. In total, the gas hydrate-bearing strata

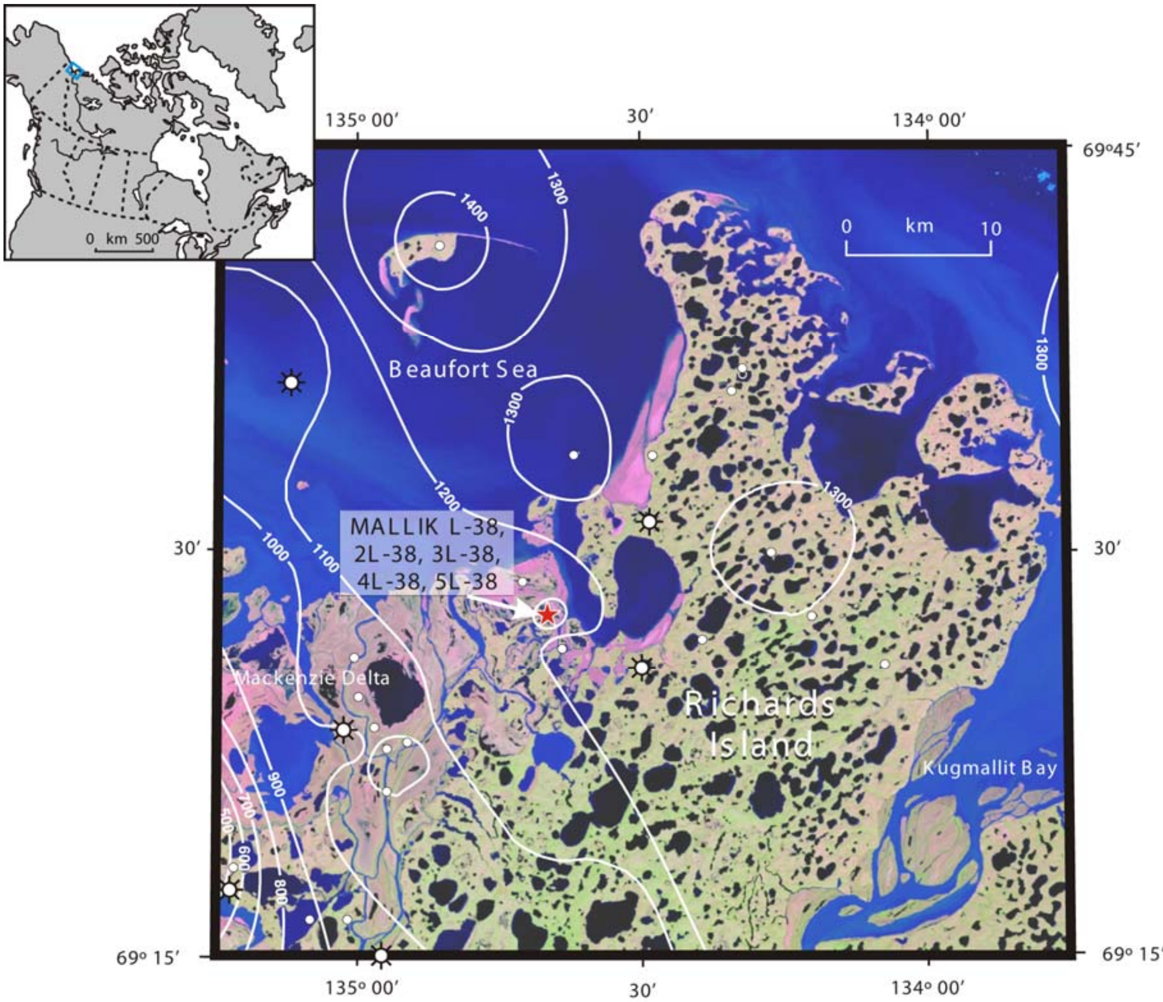

Figure 2. Location of the JAPEX/JNOC/GSC et al. Mallik 3L-38, 4L-38, and 5L-38 gas hydrate production research wells, Mackenzie Delta, Northwest Territories. Base map is a false-color mosaic constructed from a Landsat V image taken July 8, 2002. Contours indicate depth to the base of the gas hydrate stability zone in meters. Symbols include small circles as well locations, larger circles with ticks are wells containing gas hydrate [9].

was approximately 150 m thick within the depth interval from 889 to 1,101 m.

Because of the success of the 1998 Mallik 2L-38 gas hydrate research well program, the Mallik site has been elevated as an important gas hydrate production test site with execution of two additional gas hydrate production research programs: (1) The Mallik 2002 Gas Hydrate Production Research Well Program, and (2) 2006-2008 JOGMEC/NRCan Mallik Gas Hydrate Production Research Program.

In June of 2005, the partners in the Mallik 2002 Gas Hydrate Production Research Well Program publicly released the results of the first modern, fully integrated field study and production test of a natural gas hydrate accumulation [9]. The 2002 Mallik International Consortium was composed of the Japan Oil Gas and Metals National Corporation, Geological Survey of Canada, U.S. Geological Survey, U.S. Department of Energy, GeoForschungZentrum-Potsdam, the Indian Ministry of Petroleum Geology and Natural Gas, Gas Authority India Ltd, and the International Continental Scientific Drilling Program. From December 25, 2001 through March 15, 2002 the

Mallik 2002 Gas Hydrate Production Research Well Program drilled three wells (the JAPEX/JNOC/GSC et al. Mallik 3L-38 and 4L-38 observation wells and Mallik 5L-38 gas hydrate production test well) in the Mallik Gas Hydrate Field on Richard's Island, in the Mackenzie Delta, Northwest Territories, Canada.

The Mallik 5L-38 well cored and recovered gas hydrates and associated sediments from an interval between 880-1150 m depth (Figure 3). These cores were the subject of intensive examination by members of the Mallik Partnership, including scientists and engineers enabled by the International Continental Drilling Program. Detailed information on the geology, geochemistry, geotechnical and microbiological properties of gas hydrate bearing sediments was complemented by an extensive research geophysics program, which included both surface seismic surveys and downhole logging studies. This body of scientific data was designed to complement a novel production testing program, providing the world's most detailed scientific and engineering data set describing the occurrence and production characteristics of gas hydrates.

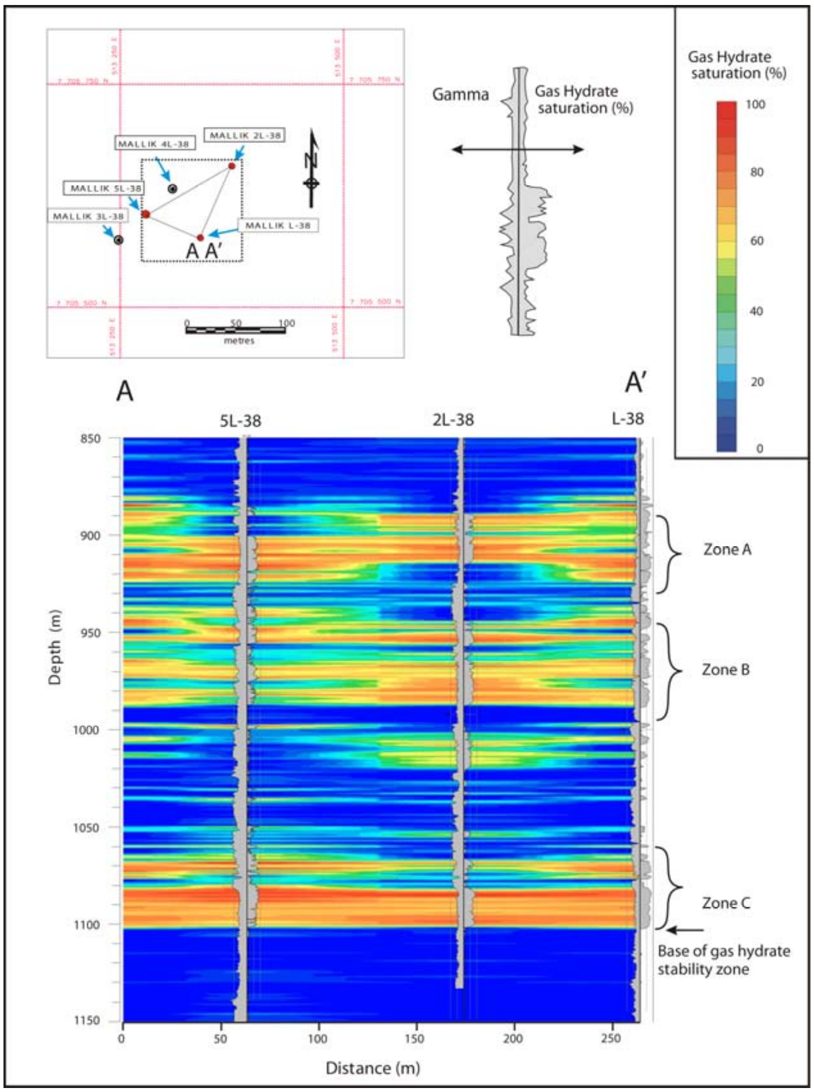

Figure 3. Fence diagram showing well-log-derived gas hydrate concentrations and natural gamma-ray logs for Imperial Oil Ltd. Mallik L-38, JAPEX/JNOC/GSC Mallik 2L-38, and JAPEX/JNOC/GSC et al. Mallik 5L-38. The well locations are shown on the location map [9].

Over 150 m of high quality gas hydrate cores were collected during the Mallik 2002 program allowing for a wide variety of studies that ranged from assessing the macroscopic to microscopic properties of the reservoir sediments (Figure 4). New work included investigations of the kinetics of gas hydrate dissociation from the solid to the gaseous form, studies of the petrophysical properties, investigations of the molecular chemistry and geotechnical properties such as

Figure 4. Photograph of a gas-hydrate-bearing rock core from the Mallik 5L-38 Gas Hydrate Research Well. Note that the gas hydrate is the white material filling the void spaces in this conglomerate (photo courtesy of the Mallik 2002 Gas Hydrate Production Research Well Program).

compressive strengths and stress regime. A wide range of geophysical studies was carried out to quantify gas hydrate distribution. A key aspect of this program was to test new geophysical tools, as methods to remotely quantify gas hydrates using a variety of geophysical surveys must be proven. Fiber optics instrumentation documented the geothermal regime with meter-scale precision. Surface, downhole and cross-hole seismic studies were carried out as were a number of advanced well log studies. Downhole measurements allowed for direct estimates of in situ permeability, gas hydrate content and investigations of the occurrence of natural fractures.

Rather than carry out long term production testing during the Mallik 2002 effort, a decision was made by the partners to conduct carefully controlled production experiments. The response of gas hydrates to heating and depressurization was evaluated with careful attention to accurately measure both input conditions and reservoir responses. The overall goal was to combine the science and production program to allow for calibration and refinement of reservoir simulation models capable of predicting long-term reservoir response. Pressure draw down experiments were designed to study the response of gas hydrate to a reduction in formation pressure conditions. The results of three short duration gas hydrate tests demonstrate that gas can be produced from gas hydrates with different concentrations and characteristics, exclusively through pressure stimulation. The data supports the interpretation that the gas hydrates are much more permeable and conducive to flow from pressure stimulation than previously thought. In one test, the gas production rates were substantially enhanced by artificially fracturing the reservoir. Thermal stimulation experiments were designed to destabilize gas hydrates by using circulated hot water to increase the in situ temperature. A five-day experiment was undertaken within a 17-m-thick section of highly concentrated gas-hydrate-bearing strata. Gas was continuously produced throughout the test at varying rates with maximum flow rate reaching 1500 cubic meters per day (Figure 5). The total volume of gas flowed was small reflecting that the test was a controlled production experiment rather than a long duration well test.

Before the Mallik 2002 project, first order thermodynamic computer models had been developed to evaluate gas hydrate production by thermal stimulation and depressurization. These models predicted that gas could be produced from gas hydrates at sufficient rates to make them a technically recoverable resource. However, the economic costs associated with these types of enhanced gas recovery techniques were poorly understood. The Mallik 2002 production research well program proved for the first time that gas production from gas hydrates is technically feasible. The Mallik 2002 thermal and depressurization production data have allowed the calibration of several reservoir models used to simulate the thermal and depressurization tests. Part of the calibration process has been the recognition that gas hydrate deposits are much

Figure 5. Photograph of the gas flare from the thermal gas hydrate production test in the Mallik 5L-38 Gas Hydrate Research Well (photo courtesy of the Mallik 2002 Gas Hydrate Production Research Well Program).

more permeable than previously thought, that they contain natural fractures, and that they may be fractured artificially. Calibrated models must therefore include full appraisal of the unique attributes of the specific gas hydrate field. The Mallik data allowed for the rational assessment of the production response of a gas hydrate accumulation if the various tests were extended far into the future. These studies show that among the possible techniques for production of natural gas from in situ gas hydrates, depressurization will produce more gas than just heating the formation. However, the combination of heating and depressurizing the gas hydrate at the same time will produce the greatest amount of gas. Project-supported gas hydrate computer production simulations, including those performed by Lawrence Berkeley National Laboratory, have shown that under certain geologic conditions gas can be produced from gas hydrates at very high rates, exceeding several million cubic feet of gas per day.

The following discussion dealing with the 2006-2008 JOGMEC/NRCan Mallik Gas Hydrate Production Research Program has been taken almost entirely from a news article appearing in the Spring/Summer 2007, U.S. Department of Energy, Office of Fossil Energy, National Energy Technology Laboratory, Fire in the Ice, Methane hydrate newsletter (available at http://www.netl.doe.gov/technologies/oil-gas/publications/Hydrates/Newsletter/HMNewsSpringSummer07optmiized.pdf; viewed August 16, 2007). The 2006-2008 JOGMEC/NRCan Mallik Gas Hydrate Production Research Program is being conducted to mainly monitor long term production behavior of gas hydrates. The Japan Oil, Gas and Metals National Corporation (JOGMEC) and NRCan are leading this research program. Aurora College/Aurora Research Institute is acting as the operator for the field program. The primary objective of the winter 2007 field activities was to install equipment and instruments to allow for long term production testing of several gas hydrate intervals during the winter of 2007-2008. Drilling rigs were used to reenter and deepen the Mallik 2L-38 and Mallik 3L-38 wells (Figure 3). Each well was also logged with various tools to establish formation properties prior to testing. After completing operations in the Mallik 2L-38 and 3L-38 wells a short pressure draw down production test was conducted to evaluate equipment performance and short term producibility of the gas-hydrate-bearing section. A 12-m-thick gas hydrate interval, near the base of the gas hydrate stability zone, was tested for 60 hours. The test results were described as “encouraging”, documenting “robust” gas flow rates. Important observations were also made in terms of produced water and the sediment response to production. The JOGMEC/NRCan Mallik gas hydrate production research program also conducted 2007-2008 winter operations, but no results have been reported on this recent activity.

North Slope, Alaska, USA – Eileen Gas Hydrate Accumulation

The North Slope of Alaska encompasses all of the land north of the Brooks Range drainage divide and is generally subdivided into three physiographic provinces, from south to north: the Brooks Range, the Foothills, and the Coastal Plain. The three main structural elements that compose the North Slope are the Brooks Range orogen, the Colville trough, and the Barrow arch, all of which correspond generally to respective physiographic provinces. The geology and petroleum geochemistry of the rocks on the North Slope of

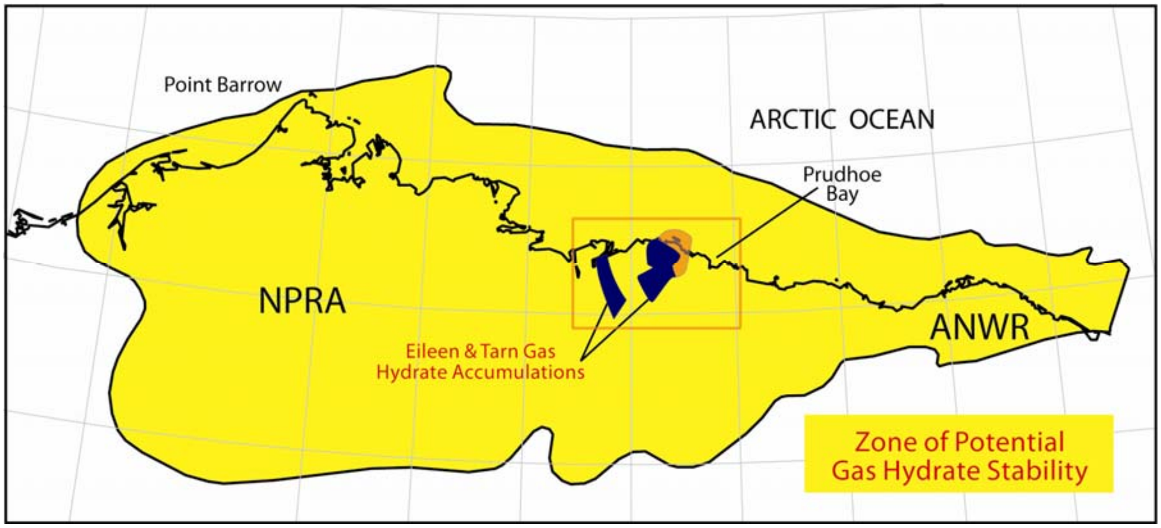

Figure 6. Map of the Alaska North Slope gas hydrate stability zone. Also shown is the location of the Eileen and Tarn gas hydrate accumulations [18].

Alaska are described in considerable detail in a number of publications [17].

On the North Slope, the subsurface temperature data needed to assess the distribution of the gas hydrate stability zone comes from high-resolution, equilibrated well-bore surveys in 46 wells and from well log estimates of the base of ice-bearing permafrost in 102 other wells [18]. The methane-hydrate stability zone in northern Alaska, as mapped in Figure 6, covers most of the North Slope. The offshore extent of the gas-hydrate stability zone is not well established; however, "relic" permafrost is known to exist on the Beaufort Sea continental shelf to a present water depth of 90 m [4].

Before the recently completed coring and downhole logging operations in the BP Exploration (Alaska) Mount Elbert well in Milne Point, the only direct confirmation of gas hydrate on the North Slope was obtained in 1972 with data from the Northwest Eileen State-2 well located in the northwest part of the Prudhoe Bay Field. Studies of pressurized core samples, downhole logs, and the results of formation production testing have confirmed the occurrence of three gas-hydrate-bearing stratigraphic units in the Northwest Eileen State-2 well [18]. Gas hydrates are also inferred to occur in an additional 50 exploratory and production wells in northern Alaska based on downhole log responses calibrated to the known gas hydrate occurrences in the Northwest Eileen State-2 well. Many of these wells have multiple gas-hydrate-bearing units, with individual occurrences ranging from 3- to 30-m-thick. Most of the well-log inferred gas hydrates occur in six laterally continuous sandstone and conglomerate units; all are geographically restricted to the area overlying the eastern part of the Kuparuk River Field and the western part of the Prudhoe Bay Field (Figure 7). The six gas-hydrate-bearing sedimentary units have each been assigned a reference letter, Units A through F, with Unit A being the stratigraphically deepest (Figure 7). Three-dimensional seismic surveys and downhole logs from wells in the western part of the Prudhoe Bay Field indicate the presence of several large free-gas accumulations trapped stratigraphically downdip below four of the log-inferred gas hydrate units (Figure 7; Units A through D). The total mapped area of all six gas hydrate occurrences is about 1,643 km^2; the areal extent of the individual units range from 3 to 404 km^2. The volume of gas within the gas hydrates of the Prudhoe Bay-Kuparuk River area, which has come to be known as the Eileen Gas Hydrate Accumulation, is estimated to be about 1.0 to 1.2 trillion cubic meters, or about twice the volume of known conventional gas in the Prudhoe Bay Field [18].

The 1995 National Oil and Gas Resource Assessment, conducted by the U.S. Geological Survey, focused on assessing the undiscovered conventional and unconventional resources of crude oil and natural gas in the United States. This assessment included for the first time a systematic resource appraisal of the *in-place* natural gas hydrate resources of the United States onshore and offshore regions [19]. The onshore portion of the assessment dealt with most of northern Alaska, in which it was estimated that there may be as much as 590 trillion cubic feet of in-place gas trapped in gas hydrates.

Under the Methane Hydrate Research and Development Act of 2000 (renewed in 2005), the U.S. Department of Energy (DOE) funds laboratory and field research on both Arctic and marine gas hydrates. Among the current Arctic studies, BP Exploration (Alaska), Inc. and the DOE have undertaken a project to characterize, quantify, and determine the commercial viability of gas hydrates and associated free gas resources in the Prudhoe Bay, Kuparuk River, and Milne Point field areas on the Alaska North Slope. Ultimately, this project could determine if gas hydrates can become a part of the Alaska North Slope gas-resource portfolio.

The following discussion dealing with the BP Exploration (Alaska) Inc. (BPXA) Mount Elbert Gas Hydrate Stratigraphic Test Well has been taken almost entirely from a news article appearing in the Winter 2007, U.S. Department of Energy, Office of Fossil Energy, National Energy Technology Laboratory, Fire in the Ice, Methane hydrate newsletter (available at http://www.netl.doe.gov/technologies/oil-gas/publications/Hydrates/Newsletter/HMNewsWinter07.pdf; viewed August 16, 2007). On February 18, 2007, a team of scientists concluded an extensive data collection program in the Mount Elbert Gas Hydrate Stratigraphic Test Well drilled in the Milne Point area on the Alaska North Slope; which yielded one of the most comprehensive datasets yet compiled on naturally-occurring gas hydrates. This project began in earnest in 2002, following BPXA's response to a DOE request for proposals to evaluate the gas hydrate resources on the North Slope. Over the following three years, the project team conducted regional geological, engineering, and production modeling studies through collaborations with the University of Alaska (Fairbanks), the University of Arizona, and Ryder-Scott Company. In 2005, extensive analysis of BPXA's proprietary 3-D seismic data and integration of that data with existing well log data (enabled by collaborations with the U.S. Geological Survey, the Bureau of Land Management, and Interpretation Services, Inc.), resulted in the identification of more than a dozen discrete and mapable gas hydrate accumulations within the Milne Point area. Because the most favorable of those targets was a previously undrilled, fault-bounded accumulation, BPXA and the DOE decided to drill a vertical stratigraphic test well at that location (named the "Mount Elbert" prospect) to acquire critical reservoir data needed to develop a longer-term production testing program.

The Mount Elbert gas hydrate stratigraphic test well was designed as a 22-day program with the planned acquisition of cores, well-logs and downhole production test data. A surface hole was first drilled and cased to a depth of 595 m. The well was then continuously cored to a depth of 760 m with chilled oil-based drilling fluid using the ReedHycalog *Corion* wireline-retrievable coring system. This core system delivered 85 percent recovery through 154 m of gas hydrate and water-bearing sandstone and shale. The coring team processed these cores on site, and collected subsamples for analyses of pore water geochemistry, microbiology, gas chemistry, petrophysical properties, and thermal and physical properties. Core samples were also stored in liquid nitrogen or transferred to pressure vessels for future study of the preserved gas hydrates. After coring, the well was reamed and deepened to a depth of 915 m, and the well was surveyed with a research-level wireline logging program including magnetic resonance and dipole acoustic logging, resistivity scanning, borehole electrical imaging, and advanced geochemistry logging. Following logging, Schlumberger Modular Dynamic Testing (MDT) was conducted at four open-hole stations in two sandstone reservoirs. Each test consisted of flow and shut-in periods of varying lengths, with one lasting for more than 13 hours. Gas was produced from the gas hydrates in each of the tests.

Gas hydrates were expected and found in two

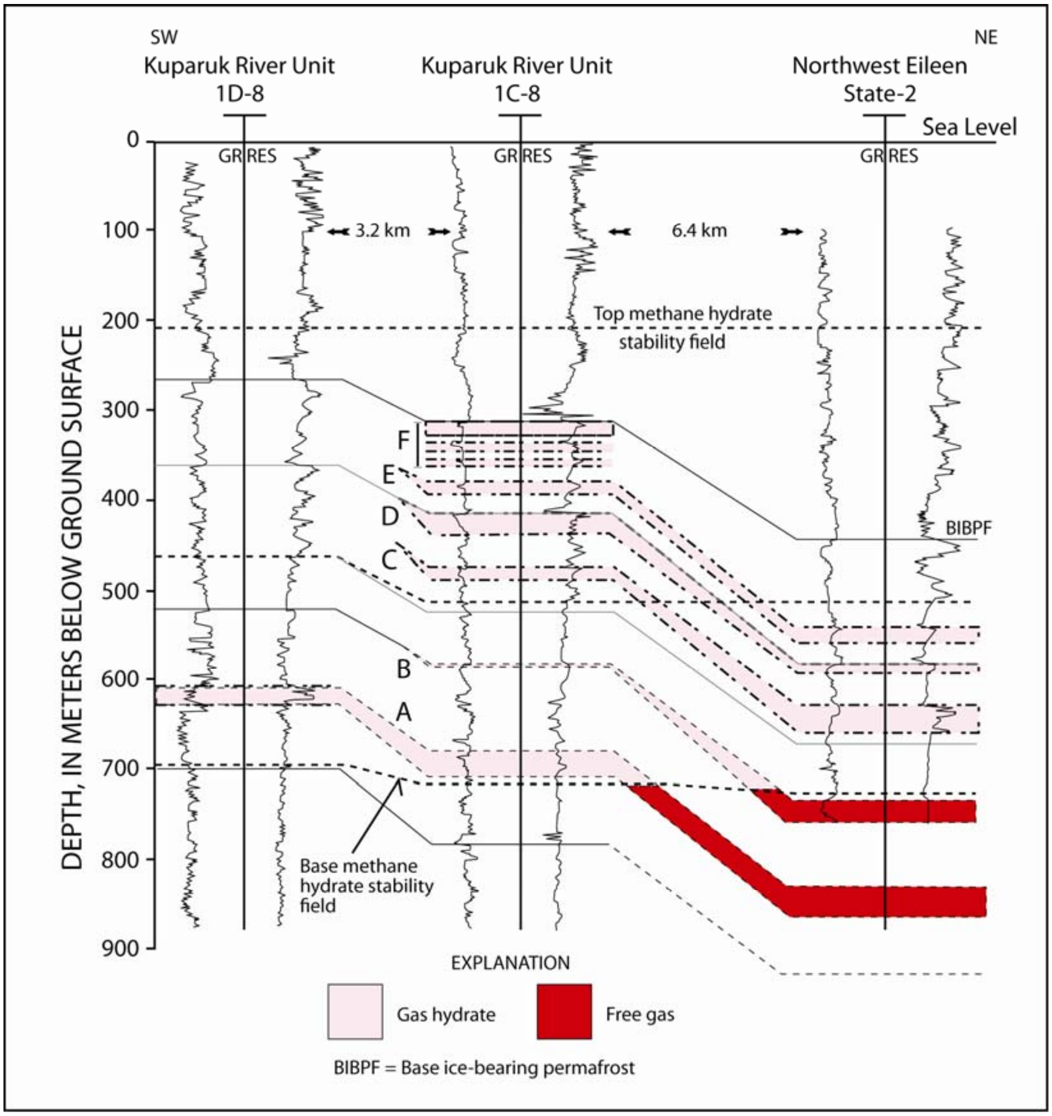

Figure 7. Cross section showing the lateral and vertical extent of gas hydrates and underlying free-gas occurrences in the Prudhoe Bay-Kuparuk River area in northern Alaska. The gas-hydrate-bearing units are identified with the reference letters A through F [18].

stratigraphic sections (Figure 7). An upper zone, (Unit D) contained ~14 m of gas hydrate-bearing reservoir-quality sandstone. A lower zone (Unit C), contained ~16 m of gas hydrate-bearing reservoir. Both zones displayed gas hydrate saturations that varied with reservoir quality as expected, with typical values between 60 percent and 75 percent. This result conclusively demonstrated the soundness of the gas hydrate prospecting methods developed primarily at the U.S. Geological Survey. Presently, the project research partners are in the process of fully analyzing and integrating all the data collected from the Mount Elbert test well, including re-calibration of the initial geological and seismic models for the site. These data will then be used by BPXA and the DOE to determine if, where, and when to proceed into the next phase of the project— currently envisioned as a long-term production testing program to determine reservoir deliverability under a variety of production/completion scenarios. This effort also includes reservoir simulations of gas hydrate production responses and evaluation of various production testing options as part of an ongoing DOE-sponsored international gas hydrate production computer code comparison study (see the following web site for additional information: http://www.netl.doe.gov/technologies/oil-gas/FutureSupply/MethaneHydrates/MH_CodeCompare/MH_CodeCompare.html; viewed August 16, 2007).

Also in northern Alaska, the U.S. Geological Survey is participating in a gas hydrate energy assessment project with the Bureau of Land Management and the Alaska Division of Geological and Geophysical Surveys. In this cooperative research project the energy resource potential of selected gas-hydrate/free-gas accumulations on public lands in northern Alaska are being evaluated. For example, the production testing and modeling efforts in support of the BPXA-DOE Mount Elbert test well project are being incorporated into the USGS North Slope gas hydrate assessment effort. Information from this study along with other gas hydrate production modeling studies are being used to assess and characterize the gas hydrate potential in the National Petroleum Reserve Alaska, Arctic National Wildlife Refuge, and the State lands. The goal of this joint project is to assess the recoverable resource potential of gas hydrates in northern Alaska.

West Siberia, Russia – The Messoyakha Field

The Messoyakha Field, a gas field located in the northern part of the West Siberian Basin, is often used as an example of a hydrocarbon accumulation from which gas has been produced from in-situ natural gas hydrates. Production data and other pertinent geologic information have been used to document the presence of gas hydrates within the upper part of the Messoyakha field [20]. It has also been suggested that the production history of the Messoyakha field demonstrates that gas hydrates are an immediate producible source of natural gas, and that production can be started and maintained by conventional methods. Long-term production from the gas-hydrate part of the Messoyakha field is presumed to have been achieved by a simple depressurization scheme. As production began from the lower free-gas portion of the Messoyakha field in 1969, the measured reservoir pressures followed predicted decline relations; however, by 1971 the reservoir pressures began to deviate from expected values. This deviation has been attributed to the liberation of free-gas from dissociating gas hydrates. Throughout the production history of the Messoyakha field, it is estimated that about 36% (about 5 billion cubic meters) of the gas withdrawn from the field has come from the gas hydrates [20]. Recently, however, several studies suggest that gas hydrates may not be contributing to gas production in the Messoyakha field [21].

CONCLUSIONS

Despite the apparent obstacles to the development of gas hydrate resources, it is important to remember that extraordinary technological developments in the petroleum industry – three-dimensional seismic techniques, secondary recovery methods, and horizontal drilling, for example – have allowed the extraction of resources once thought to be unavailable. Natural gas hydrates may also become economically extractable. On-shore Canada and Alaska are proven exploration targets for gas hydrates. The first commercial production of gas hydrates is likely to occur in either northern Alaska or Canada, where gas from gas hydrates will either support local oil and gas field operations, or be available for commercial sale if and when suitable gas pipelines are constructed. It is important to highlight, that on the North Slope of Alaska, critical drilling and transportation infrastructure exists, which will allow gas hydrate prospects to be drilled and produced from existing facilities.

The timing for expected commercial production of hydrates is uncertain. The U.S. Department of Energy has estimated that gas production from gas hydrates could begin around 2015. In September of 2003, the National Petroleum Council reported that we will not likely see significant production from gas hydrates until sometime beyond 2025. However, initial production from gas hydrates will most likely occur much sooner. Estimates vary on when gas hydrate production will play a significant role in the total world energy mix; however, it is possible that gas hydrates will be able to provide a sustainable supply of gas for the world's future energy needs.

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