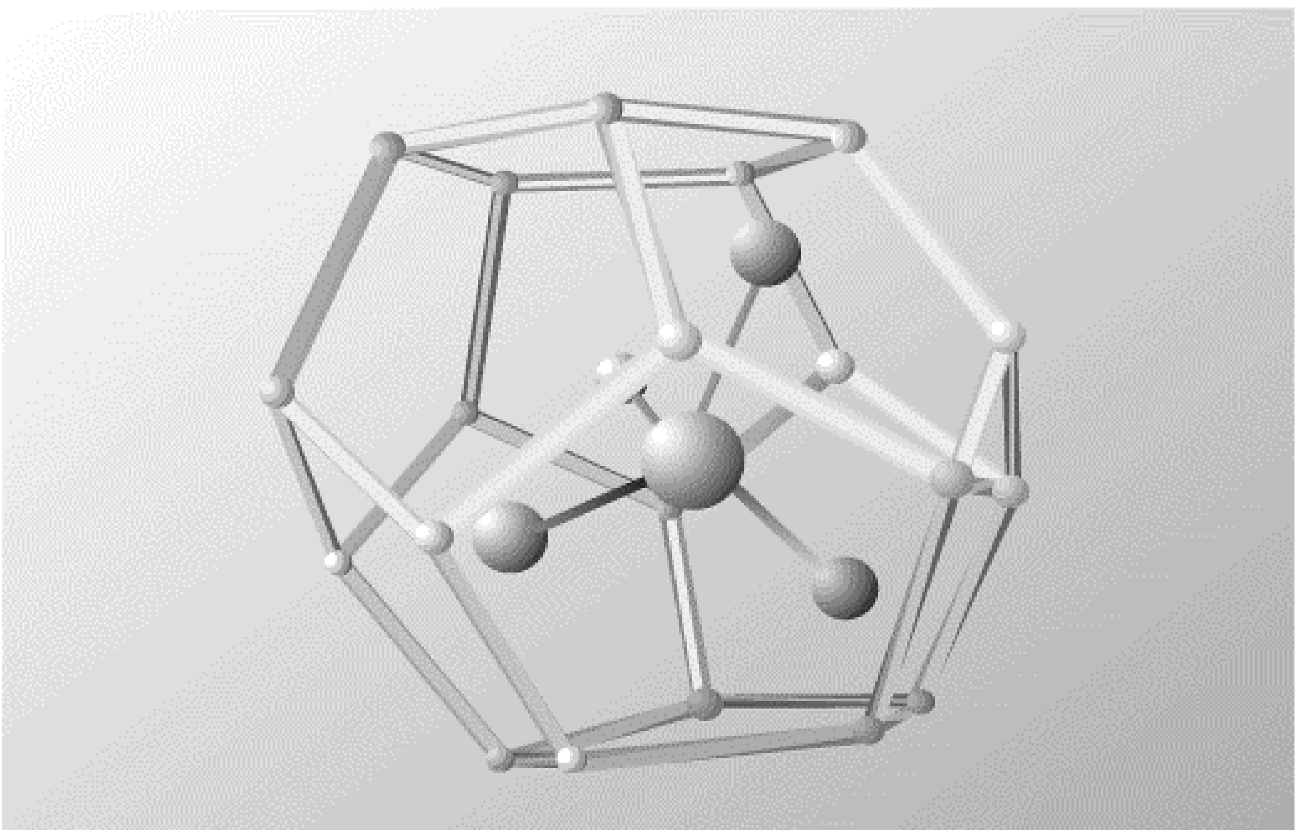
OCS Report
MMS 2000-017

Oceanic Gas Hydrate Research and Activities Review



U.S. Department of the Interior
Minerals Management Service
Gulf of Mexico OCS Region

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MMS 2000-017

Oceanic Gas Hydrate Research and Activities Review

Preparers

Mary C. Boatman
and
Jennifer Peterson

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ACRONYMS

AGHRP	Applied Gas Hydrate Research Program
APD	Application for Permit to Drill
API	American Petroleum Institute
BAST	Best Available and Safe Technologies
BLM	Bureau of Land Management
BSR	Bottom Simulating Reflector
CNES	Comprehensive National Energy Strategy
CSMHC	Colorado School of Mines Hydrate Consortium
DOE	Department of Energy
EA	Environmental Assessment
EEZ	Exclusive Economic Zone
EIS	Environmental Impact Statement
FY	Fiscal Year
GAIL	Gas Authority of India Ltd
GERG	Geochemical and Environmental Research Group
GMHRC	Gulf of Mexico Research Consortium
GOMR	Gulf of Mexico Region
GRI	Gas Research Institute
H.R.	House of Representatives
HSZ	Hydrate Stability Zone
IADC	International Association of Drilling Contractors
INTERMAR	International Activities and Marine Minerals Division
JAPEX	Japan Petroleum Exploration Company Ltd.
JOI	Joint Oceanographic Institutions, Inc.
JOIDES	Joint Oceanographic Institutions for Deep Earth Sampling
MCF	Million Cubic Feet
MMS	Minerals Management Service
MOU	Memorandum of Understanding
NEPA	National Environmental Policy Act
NGSA	Natural Gas Supply Association
NRL	Naval Research Laboratory
NSF	National Science Foundation
NTL	Notice to Lessees and Operators
ODP	Ocean Drilling Program
OCS	Outer Continental Shelf
OOC	Offshore Operators Committee
PCAST	President’s Committee of Advisors on Science and Technology
POE	Plan of Exploration
R&D	Research & Development

RE	Resource Evaluation
ROV	Remotely Operated Vehicle
STP	Standard Temperature and Pressure
TA&R	Technology Assessment and Research
U.S.	United States
U.S. DOE	United States Department of Energy
USGS	United States Geologic Survey

EXECUTIVE SUMMARY

Gas hydrates are ice-like crystalline structures of water that form “cages” that trap low molecular weight gas molecules, especially methane. Gas hydrates have recently attracted international attention from government and scientific communities. This document outlines the major issues surrounding gas hydrates, research initiatives that are underway around the world, and the potential information needs of and the role that Minerals Management Service (MMS) may play in future activities. Gas hydrate interests are multifaceted and intertwined. The major issues can be divided into three categories:

Safety Hazards:

- Hydrates can form on drilling equipment and in pipelines in deepwater. Plugs of hydrate can stop flow and create pressure buildup that could rupture a pipeline. Drilling equipment can become frozen, creating a hazard to workers.

- Hydrates occur naturally as surficial outcrops and as a cementing agent in sediments. They are metastable and can easily dissociate, resulting in slumping or slides.

Energy Resource:

- Methane hydrates have been located in vast quantities around the world in continental slope deposits and permafrost. If the hydrates can be economically recovered, they represent an enormous potential energy resource.

Environmental:

- Gas hydrate outcrops are associated with sensitive biological communities and may be an energy (food) source for these communities.

- Some researchers hypothesize that with slight changes in sea level and seawater temperature gas hydrates dissociate and re-form in such a way that they could release and/or sequester large volumes of methane gas, one of several greenhouse gases involved in global warming.

Many groups are actively participating in a wide variety of gas hydrate research. The Department of Energy (DOE) plans to coordinate gas hydrate research activities and provide a foundation to pursue the goal of producing methane from hydrates by the year 2015. The U.S. Geological Survey (USGS) has conducted extensive geophysical surveys and established a specialized laboratory facility to model the formation and dissociation of oceanic gas hydrates. The Naval Research Laboratory (NRL) plans to study geoacoustics; sediment stability; the relationship between faults, fluid transport, and gas hydrate formation; and dissociation. The National Science Foundation (NSF) has been funding basic gas hydrate research. The Colorado School of Mines Hydrate Consortium and Texaco’s Deep Star Consortium have been involved in gas hydrate research activities for years. Gas hydrate research and resource development are also underway in Japan, India, Canada, the United Kingdom, Germany, Brazil, Norway, and Russia.

The MMS is involved with several gas hydrate activities:

- MMS protects chemosynthetic communities from being disturbed by offshore oil and gas production, and the MMS Environmental Studies Program is funding the second of two large studies on chemosynthetic communities,

- the MMS Gulf of Mexico Region Office of Resource Evaluation (RE) is compiling a database as part of a gulf-wide mapping project on the location of known and inferred gas hydrates,

- the Center for Marine Resources and Environmental Technology (CMRET), which is funded through the International Activities and Marine Minerals Division (INTERMAR), is conducting a study to monitor gas hydrates at a selected site,

- MMS has funded several gas hydrate safety studies since the 1980's (e.g., Brian Watts Associates 1984; Yousif 1996; Makogon 1997), and

- MMS scientists and engineers currently participate in several gas hydrate university/industry consortiums, programs, and committees.

The MMS involvement in present and future gas hydrate research may focus on:

- Expanded participation in gas hydrate consortiums, programs, and committees involved in directing the future of hydrate research;

- Use of available resources to map surface anomalies that may be gas hydrates and supporting groundtruthing of this map. Results of the ongoing RE project will help geologists evaluate oil field resources, engineers evaluate geohazards to avoid, and biologists identify biologically sensitive communities.

- Awareness of increased activities in deepwater and the chances of hydrate-related accidents. Gas hydrate identification from seismic data is tenuous, and more information is needed to determine the best methods for hydrate identification from the seismic data. This information is also needed for future resource evaluation to determine if methane hydrate prospects are worth recovering.

- With the expectation that methane hydrate extraction will become a reality, the MMS will need to modify regulations and prepare environmental assessments.

PART I. Survey of Gas Hydrates Today

1. INTRODUCTION

1.1 Methane Hydrates: A Hot Topic

Gas hydrates, low molecular weight gas molecules trapped in water-ice "cages" in permafrost or subsea deposits, have gained international attention over the last few years for energy, safety, and environmental reasons. Methane, the essential component of natural gas, is the most common gas trapped in hydrates. Natural gas is an important source of clean, efficient energy, and therefore methane hydrates may represent a potential energy resource. For many years, oil and gas drilling companies have recognized gas hydrates as a hazard because of their ability to plug pipelines and wells. Gas hydrates in ocean sediments can affect seafloor stability making them a safety concern for oil and gas production equipment. Methane hydrates also raise environmental concerns. Studies have shown that they may play a role in climate change and serve as a source of sustenance for sensitive ocean floor biological communities.

In the United States, the Department of Energy (DOE), the Naval Research Laboratory (NRL), the United States Geological Survey (USGS), and several academic and industrial research groups have already initiated programs specifically aimed at investigating gas hydrates. Internationally, gas hydrate research activities and R&D spending have also increased. Aggressive research and exploration programs are underway in Japan, India, Canada, the United Kingdom, Germany, Brazil, Norway, and Russia. Currently, cost-effective production methods are not available, but research groups around the world are trying to engineer creative new techniques for economically feasible production. The potential for energy is vast and several groups are attempting to estimate its size.

The Minerals Management Service (MMS) is committed to supporting advances in offshore technologies to improve operational safety. The MMS has funded gas hydrate research regarding safety concerns related to offshore gas and oil production and is funding two ongoing projects. The majority of the gas hydrate deposits in the United States are located in waters owned by the Federal Government. Should gas hydrates be produced for energy, MMS needs to be prepared to provide guidance on how to structure methane hydrate royalty and leasing agreements, provide protection to undersea biological communities, and ensure that the appropriate safety measures are in place during production.

The MMS Solicitor's Office recently issued an opinion that states that hydrates are to be included in existing royalty and leasing agreements. Current regulations may not apply to methane hydrate production, and environmental protection policies and programmatic NEPA coverage are nonexistent. This document identifies the information needs MMS now has in relation to gas hydrate geohazards, characterization, environmental protection, and the information needs MMS can expect to have, if offshore hydrate production becomes a reality.

1.2 What is a Gas Hydrate?

Gas hydrates are naturally occurring solids composed of hydrogen-bonded water lattices that trap molecules of methane and other low molecular weight gas molecules. They form at low temperatures and high pressures. Gas hydrates form in two geologic settings: (1) on land in permafrost regions and (2) in the ocean sediment of continental margins. The primary gas of interest as a resource is methane. The volume of methane in one hydrate unit may contain the equivalent of 164 volumes of methane gas at standard pressure and temperature (STP) (Davidson et al. 1978). Kvenvolden (1993) estimates that the amount of methane stored in hydrate form on continents and on the ocean floor at roughly 10^{19} g (Figure 1). If this estimate is correct, then the amount of methane stored as methane hydrate totals approximately twice the amount of carbon in known fossil fuel deposits worldwide. Dickens et al. (1997) suggest that the methane stored at Blake Ridge, offshore South Carolina, would supply enough natural gas to sustain the United States at 1996 consumption levels for 105 years.

Offshore methane hydrates form in the hydrate stability zone (HSZ), which is a surface parallel layer that starts where the pressure and temperature conditions are in the stability range for hydrate formation (Figure 2) (Max and Lowrie, 1996). The hydrate deposit extends downward in the sediment until the temperature increases to the point where the hydrates are no longer stable. While massive hydrate deposits may be several hundred meters thick, they are pressure and temperature sensitive and can easily dissociate if the conditions change.

The presence of offshore methane hydrates is usually inferred from high amplitude seismic reflectors, called bottom simulating reflectors (BSR's), that record a phase boundary often detectable at the base of the HSZ (Max and Lowrie, 1996). The BSR is principally due to free gas trapped below the HSZ (Holbrook et al., 1996). However, the absence of a BSR does not necessarily indicate that hydrate deposits are not present. Observations in cores drilled from the Blake Ridge indicated that hydrates were present when the BSR was present and, in one case, when they were not observed (Holbrook et al., 1996). The BSR data have been the primary source used to estimate the world's reservoirs (Kvenvolden, 1993) and may be off by a factor of three or more, depending on the interpretation of the seismic data (Holbrook et al., 1996). Thus far, BSRs are known to exist in at least 22 continental margins around the world (Singh et al., 1993). Still, little is known about the geologic conditions under which hydrates form.

Methane is the most common gas trapped in hydrates, comprising 99 percent of the trapped gas (Kvenvolden, 1995). Other gases, such as carbon dioxide, propane, and ethane, can form hydrates and have been observed in the Gulf of Mexico and the Caspian Sea, where the gas hydrates contain from 3 to 79 percent non-methane gas (Kvenvolden, 1995). The source of the

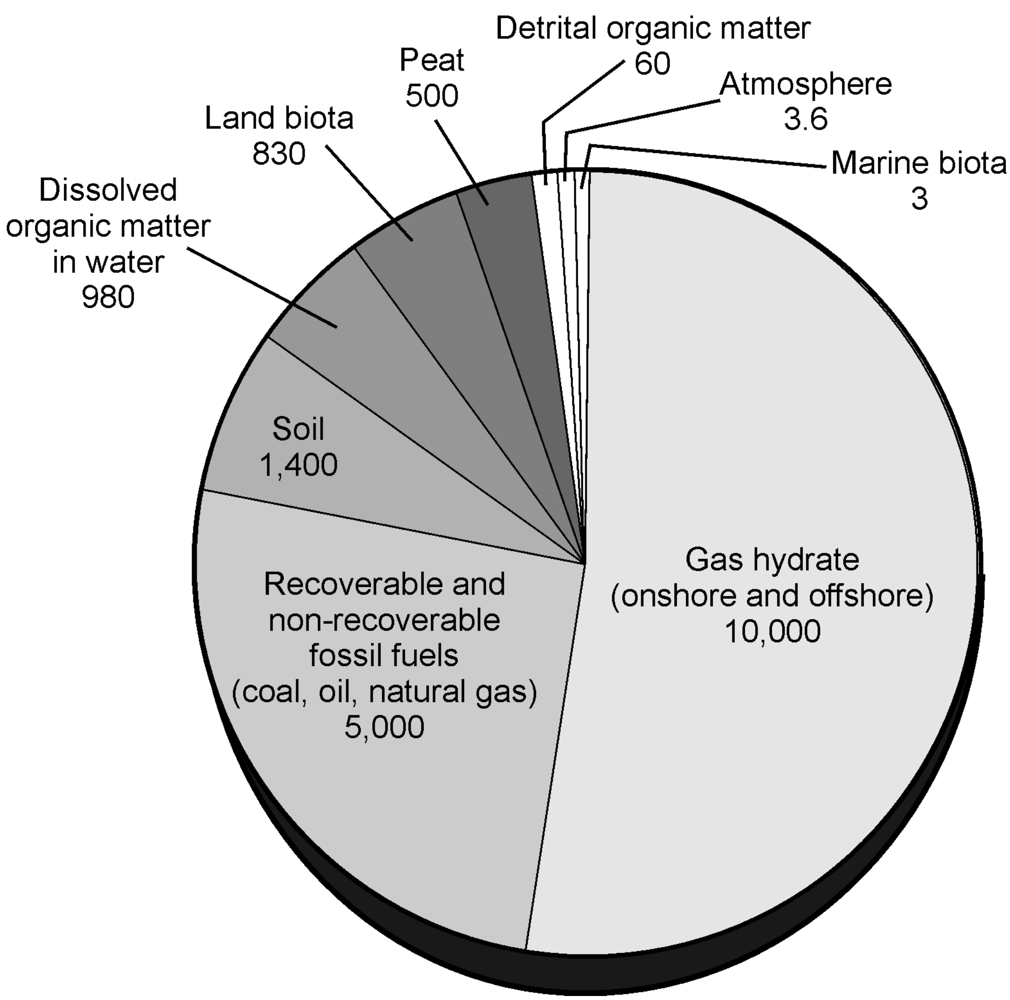


Figure 1. Distribution of worldwide organic carbon in units of 10^{15} g of carbon (from Kvenvolden, 1993).

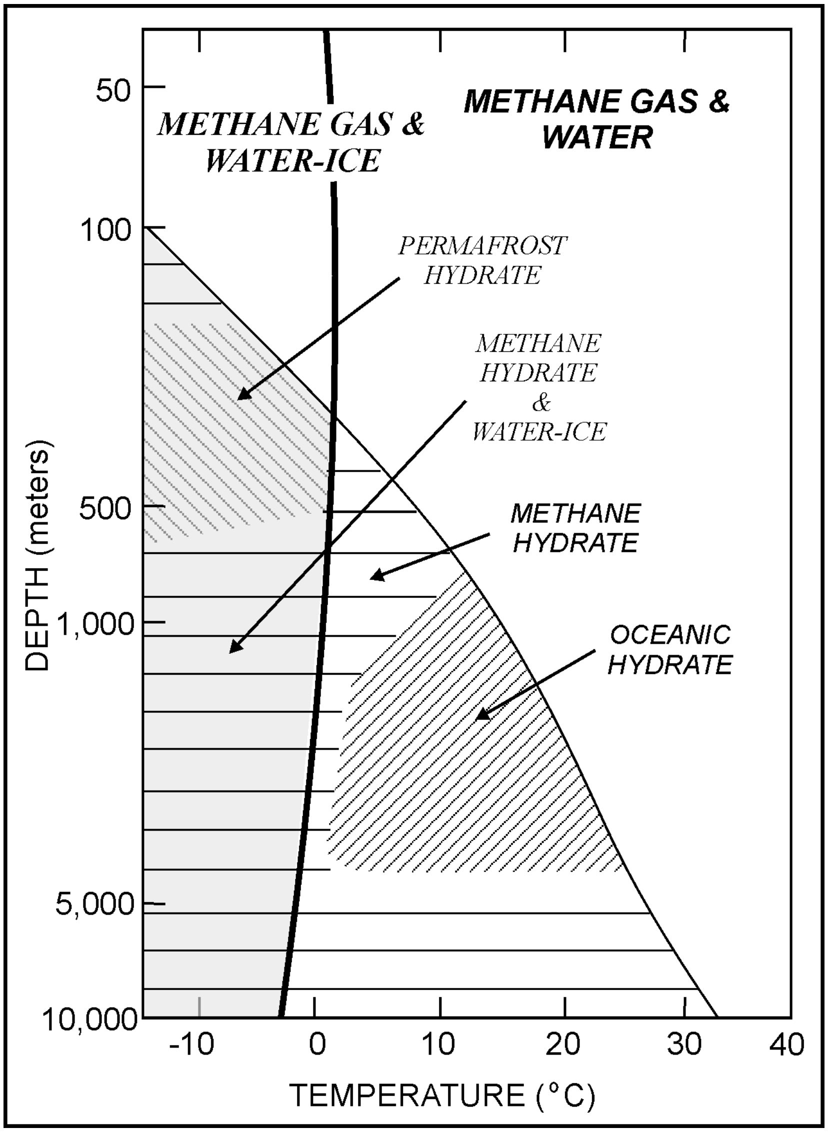


Figure 2. Gas hydrate phase diagram demonstrating the hydrate stability zone (HSZ). This diagram shows the stability fields of the water-ice-methane-hydrate system. The presence of gases (e.g., methane, ethane, propane) will shift the phase boundary to the right and the presence of chemical inhibitors (e.g., methanol) will shift the phase boundary curve to the left (from Max and Lowrie, 1996).

gas in these locations is thermogenic breakdown of hydrocarbon deposits, as opposed to the biogenic source of most methane gas hydrates. The thermogenic origin was identified by carbon isotopic studies and the presence of ethane and propane in addition to methane (Brooks et al. 1984; Sassen and MacDonald, 1997).

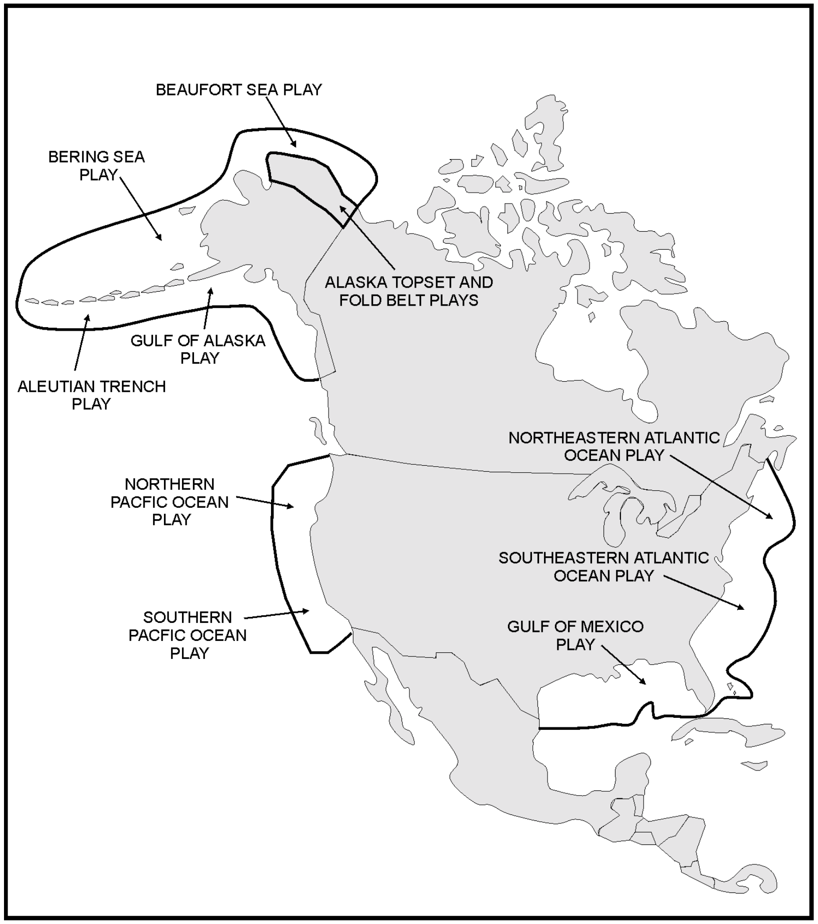
While most of the information regarding the location and extent of hydrates comes from seismic data, some direct observations have been made. The first core recovered from the Western Hemisphere with gas hydrates intact was collected during a *Glomar Challenger* cruise off the coast of Guatemala in 1981. Researchers at Texas A&M University have collected gas hydrate cores in the northwestern Gulf of Mexico (Brooks et al. 1984). Gas hydrate cores were collected for analysis along the Blake Ridge as part of the Ocean Drilling Program (ODP) LEG 164 (Paull et al., 1996), and outcrops have also been observed from submersibles in the Gulf of Mexico (MacDonald et al., 1994 and Roberts et al., 1999).

1.3 Methane Hydrate: A Resource

While the production of methane hydrates has occurred in permafrost regions in western Siberia and under test conditions in the Prudhoe Bay-Kuparak River field in Alaska, the world has yet to produce offshore hydrates (Max and Lowrie, 1996). The technology does not exist to extract methane hydrates, primarily because there is no real understanding of the geological conditions under which they exist (Max and Cruickshank, 1999).

India, Japan, and other nations have initiated research programs to pursue the recovery of methane from hydrate deposits. The Japanese government started a methane hydrate program in 1995. This program was partially funded and supported by the USGS, DOE, and the Japan Petroleum Exploration Co. Ltd. (JAPEX). In the winter of 1998, two holes were drilled into the MacKenzie Delta permafrost in Canada to investigate gas hydrates as part of this program. In 1996, the Indian Government organization Gas Authority of India Ltd. (GAIL) also began a gas hydrate exploration and assessment program.

In the United States, offshore deposits have been identified in Alaska, all along the West Coast, in the Gulf of Mexico and, most notably, along Blake Ridge. Figure 3 shows the United States Geological Survey (USGS) estimates from the plays around the United States, with Alaska having more than 50 percent of the reserves. International offshore deposits have been located on the eastern and western continental margins of Japan, the Black Sea, and offshore Peru in the Middle America Trench, among other locations (Figure 4). Onshore gas hydrates have been found in permafrost regions such as western Siberia, the MacKenzie Delta in Canada, Lake Baikal in Russia, and the North Slope of Alaska at a range of depths from 130 to 2,000 meters below the surface (Kvenvolden, 1988).



Plays	Mean Estimates (Trillion Cubic feet, Tcf)	Percentage Of Total U. S. Resource
Atlantic Ocean Province	**51,831**	**16.1**
- Northeastern Atlantic Ocean Play	30,251	9.4
- Southeastern Atlantic Ocean Play	21,580	6.7
Gulf of Mexico Province	**38,251**	**12.0**
- Gulf of Mexico Play	38,251	12.0
Pacific Ocean Province	**61,071**	**19.1**
- Northern Pacific Play	53,721	16.8
- Southern Pacific Play	7,350	2.3
Alaska Offshore Province	**168,449**	**52.6**
- Beaufort Sea Play	32,304	10.0
- Bering Sea Play	73,289	23.0
- Aleutian Trench Play	21,496	6.6
- Gulf of Alaska Play	41,360	13.0
OFFSHORE PROVINCES TOTAL	**319,602**	**99.8**
Alaska Onshore Province	590	0.20
- Topset Play–State Lands & Waters	105	0.034
- Topset Play–Federal Waters	43	0.013
- Fold Belt Play–State Lands & Water	414	0.13
- Fold Belt Play-Federal Waters	28	0.011
ONSHORE PROVINCES TOTAL	**590**	**0.20**
UNITED STATES TOTAL	**320,192**	**100**

Figure 3. USGS estimates of the United States in-place gas resources within gas hydrates (from U.S. DOE, 1998a).

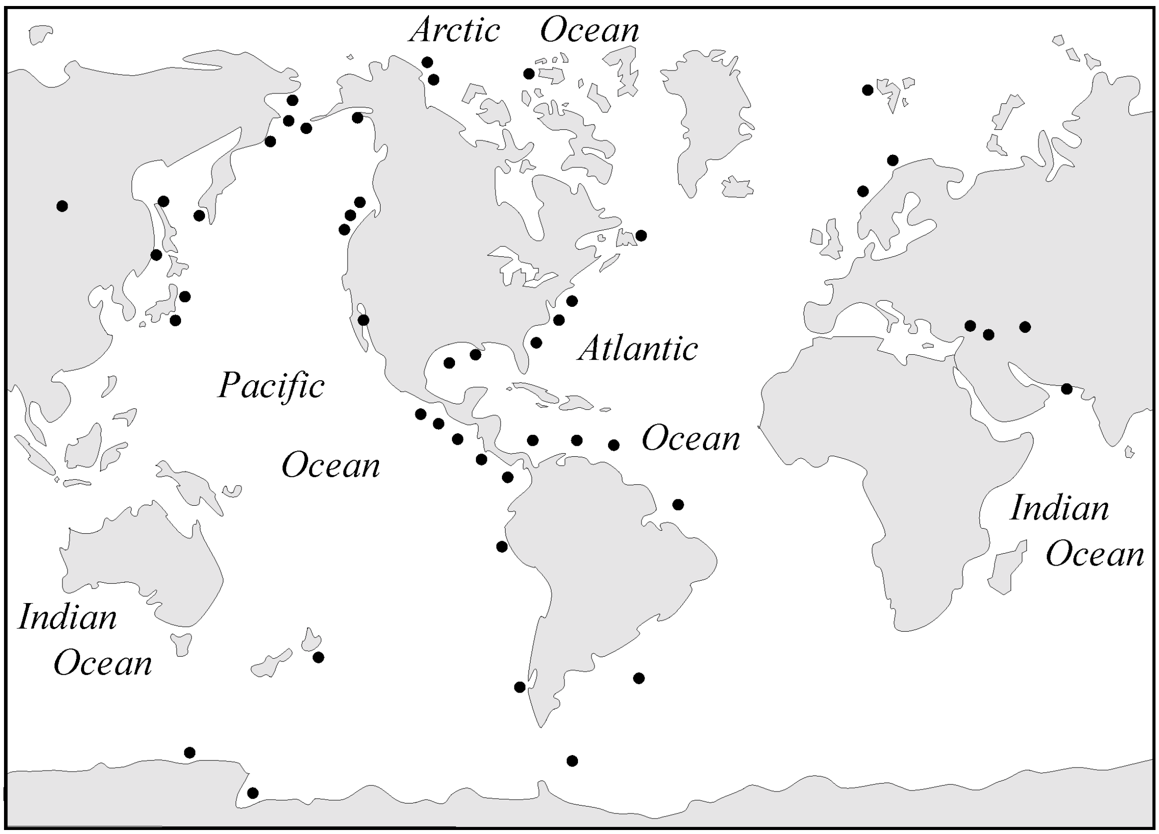


Figure 4. Locations of inferred and observed deepwater submarine gas hydrates (from Kvenvolden, 1993).

Some methane gas has been produced from gas hydrate dissociation in the Messoyakha Field in the permafrost region of Western Siberia. The field began gas production in 1970, and was shut in 1978. During production, formation gas pressure decreased normally. During the shut-in period from 1978 to 1980, formation gas pressure rebounded somewhat. When the field went back on production in 1980, formation pressure was maintained at a higher level than the theoretical estimation for the field. This discrepancy was interpreted as the contribution of methane gas from the dissociation of gas hydrates adjacent to the zone of production (http://www.aist.go.jp/GSJ/dMG/hydrate/Messoyakha.html).

1.4 Gas Hydrate: A Hazard

Gas hydrate formation in pipelines and on equipment is a safety hazard to operators in deepwater. Dr. Dendy Sloan at the Colorado School of Mines and others are conducting research to understand how hydrates form in pipelines and what kinds of new solutions are available to dissociate hydrate plugs. Among the new prospects for removing hydrate plugs are kinetic inhibitors and anti-agglomerates. Kinetic inhibitors are water-soluble polymers that slow the hydrate formation from hours to days. Anti-agglomerates are surfactants that cause hydrates to form in small, dispersed crystalline structures instead of a solid plug. Kinetic inhibitors and anti-agglomerates are just now becoming available to industry.

Methane hydrates also cause another kind of hazard, seafloor instability. The presence of gas hydrates in ocean sediments affects the geological and physical properties of the seafloor including shear strength, porosity, permeability, acoustic velocity, fluid composition, and fluid flow (Dillon et al. 1998). Hydrates can fill pore spaces and impart mechanical strength to sediments by cementing grains together (Max and Lowrie, 1996). However, since they are pressure and temperature sensitive, the gas hydrates that once provided support can dissociate quickly with slight changes in pressure or temperature, resulting in slumping and slides (Dillon et al. 1998). These slumps and slides pose a threat to pipelines and other oil and gas production equipment on the seafloor.

The instability of gas hydrate outcrops in the Gulf of Mexico has been observed (MacDonald et al., 1994 and Roberts et al., 1999). Large sections of hydrate outcrops have disappeared, between annual visits by submersibles, either by dissociation or breaking off and floating away, clearly demonstrating their ephemeral nature and potential as a safety hazard.

1.5 Methane Hydrate: Global Warming

Besides the fact that gas hydrates pose hazards for offshore oil and gas operations, other factors have led to a renewed interest in their study, including an international push for cleaner fuels and enhanced international emphasis on the global climate change debate. Researchers argue that increases in the concentration of atmospheric greenhouse gases (such as methane) will result in increases in the amount of heat retained by the Earth’s atmosphere. Gas hydrates may influence global climate change when the methane stored in hydrate form is released in large quantities during dissociations triggered by slumps or slides (Paull et al., 1991 and Dillon et al., 1998). Haq (1997) notes that Antarctica ice cores indicate atmospheric methane increases that parallel global warming trends. Recently, a coring project in Antarctica resulted in a 2-mile-long core that shows that levels of greenhouse gases are higher now than at any time in the past 420,000 years. Highest levels of methane prior to recent history ranged from 650-770 ppb and are significantly lower than the current level of 1,700 ppb.

2. FEDERAL INVOLVEMENT IN METHANE HYDRATE R&D

Recognizing the potential of methane hydrates as an energy source, the President's Committee of Advisors on Science and Technology (PCAST) report to the President on *Federal Energy Research and Development for the Challenges of the Twenty-First Century* (PCAST, 1997) recommended that U.S. Federal agencies and industry allocate resources to support research into the potential of producing methane hydrates. In response to this report and others, the DOE launched a major initiative to study gas hydrates. In August 1998, the DOE Office of Fossil Energy released, *A Strategy for Methane Hydrates Research and Development* which outlines the foundation for a 10-year science and technology program (U.S. DOE, 1998a). DOE plans to coordinate hydrate research activities and provide a foundation for reaching the goal of producing methane from hydrates by the year 2015. In 1997, the Naval Research Laboratory (NRL) developed a guidance document to formulate the expansion of NRL hydrate research into a comprehensive gas hydrate research program (Max et al., 1997).

On January 28, 1999, Senate Bill S. 330, Methane Hydrate Research and Development Act of 1999, was introduced in the U.S. Senate. On April 19, 1999, the bill was passed by the Senate without amendment by unanimous consent. The bill was referred to the House of Representatives Committees on Science and Resources. A companion bill, H. R. 1753, was introduced into the House of Representatives. S. 330 promotes the research, identification, assessment, exploration, and development of methane hydrate resources. In May of 1999, several national methane hydrate experts were called on to testify on S. 330 and H. R. 1753. The testimony of these experts and a copy of the present bill, S. 330, are in Appendix 1.

3. METHANE HYDRATE RESEARCH AND RESOURCES AT MMS

3.1 Past and Ongoing Research Projects

The Technology Assessment and Research (TA&R) Program, a research arm of the MMS Regulatory Program, supports operational safety and pollution prevention research, as well as oil spill response and cleanup studies. The TA&R Program was established in the 1970's to ensure that industry operations on the Outer Continental Shelf incorporated the use of the Best Available and Safest Technologies (BAST). The MMS has funded several TA&R projects related to gas hydrates as geohazards since the 1980's.

Feasibility and Costs of Exploration and Production Systems in OCS Lease Sale 87, Diapir Field, Alaska assessed the feasibility and costs of developing exploration and production systems. Sea ice, unconsolidated sediments, soil slumping, shallow gas concentrates, subsea permafrost, gas hydrates, and ice gouges are some of the factors that will complicate development in this area. This project was a cooperative effort composed of 20 industry participants and the Minerals Management Service. A primary objective of this project was to develop a specific criterion for various target sites within the lease sale area (Brian Watt Associates, 1984).

Hydrates of Hydrocarbons reviewed the state of the art in topics such as the prevention of hydrate formation and removal of hydrates during drilling, production, transportation, and other processing of hydrocarbons. These issues will become increasingly important to the safety of operations as industry moves into the deeper parts of the Gulf of Mexico, where the colder temperatures cause more hydrate formation (Makogon, 1997).

Control of Natural Gas Hydrates developed a model to predict the rate of hydrate plug decomposition, to measure the mobility of hydrate plugs with/without kinetic inhibitors, and to characterize the morphology of gas hydrates. Depressurization (venting) and chemical injection were investigated as methods to remove hydrate blockage from subsea gas or gas condensate pipelines. A mathematical model was developed for the plug decompression process and experimentally validated. Hydrate plug decomposition by chemical injection can be an effective process for blockage removal, when decompression is not possible (Yousif, 1996).

Novel Hydrate Prediction Methods for Drilling Fluids developed a gas hydrates prediction model for drilling fluids made from salts and glycerol. The model will include two prediction methods for the hydrate temperature suppression. High-pressure hydrate equilibrium and resistivity data will be acquired in the first phase of the proposal. The second phase will involve the final development of the computer prediction model. The model will be verified against field and laboratory data (Rye-Holmboe and Yousif, 1996 and Rye-Holmboe and Yousif, 1997).

The MMS has recently funded two large-scale studies on the chemosynthetic communities that exist near oil seeps and gas hydrate outcrops in the Gulf of Mexico.

Northern Gulf of Mexico Continental Slope Chemosynthetic Communities Program first produced a literature review. Following the review, 10 different researchers studied the regional distribution of chemosynthetic communities across the continental slope in the northern Gulf of Mexico, the geologic and geophysical characterization of associated hydrocarbon deposits (including gas hydrates), and then described the habitats and ages and general ecology of the chemosynthetic communities thriving on gas hydrates near oil and gas seeps.

Stability and Change in Gulf of Mexico Chemosynthetic Communities was designed to provide MMS with the information necessary to manage the sensitive biologic communities on the ocean floor. This study provides an understanding of the processes that control the distribution, health, and succession of these communities, and the effects of fossil energy exploration (including gas hydrate disturbance) on these communities. At the regional level, this effort is focusing on the geological, chemical, and oceanographic processes that maintain the stability of these communities.

Recently, the MMS Gulf of Mexico Region Office of Resource Evaluation launched an effort to complete a Gulfwide geophysical seafloor mapping project to assist in evaluating resources in the Gulf of Mexico. This database already includes over 83 3-D seismic surveys; data from over 1,200 ocean floor core samples, some of which contain evidence of gas hydrates; and data on more than 20 pressurized gas hydrate cores sampled by Texas A&M researchers (Figure 5). As all future 3-D surveys are received, the seafloor reflector will be mapped for the entire survey as a first step in the data acquisition process, and these maps will be added to the database.

The Resource Evaluation Office of the MMS Gulf of Mexico OCS Region mapped the seafloor bottom reflector and geologic trends, including faults and faulted salt diapirs, some of which show anomalous amplitude responses, to determine if mapping this seismic data can help identify hydrocarbon reservoirs at depth. Higher seismic velocities resulting from hydrates, carbonates, and chemosynthetic communities associated with hydrocarbon seeps result in positive seismic anomalies in the seafloor reflector. This project is expected to enhance overall risk assessment, environmental protection of chemosynthetic communities, and resource evaluation.

3.2 Participation in Methane Hydrate Activities

In an effort to support an ongoing dialog between industry, government, and academia about methane hydrates, MMS is involved in several gas hydrate consortiums, programs, and committees.

<u>Gulf of Mexico Hydrate Research Consortium (GMHRC)</u>

Formed in March of 1998, the GMHRC comprises researchers from academia, industry, and the Federal Government. The Center for Marine Resources and Environmental Technology (CMRET) at the University of Mississippi in Oxford, MS, a research group associated with MMS, manages the GMHRC. A meeting of the GMHRC was held in September 1998 at MMS in New Orleans.

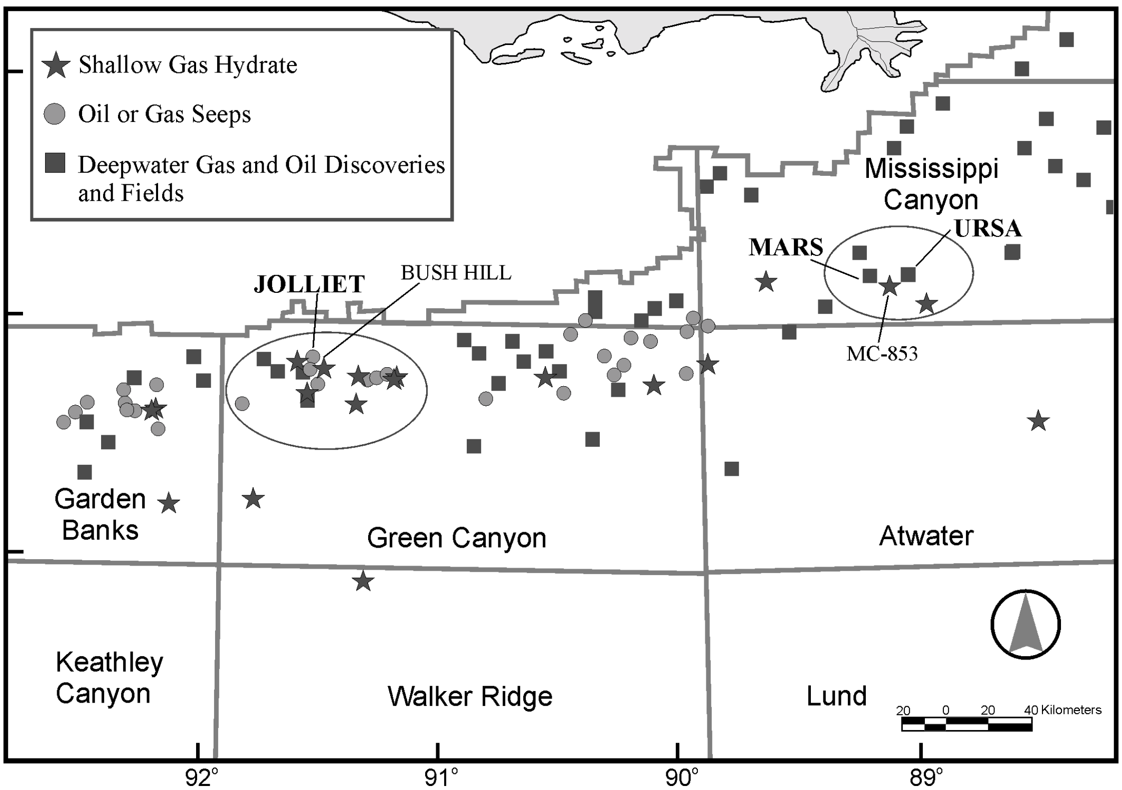


Figure 5. Map showing the location of recent Texas A&M gas hydrate drill cores with related oil and gas seeps and fields in the Gulf of Mexico (from Sassen et al., 1998).

The Center for Marine Resources and Environmental Technology (CMRET), part of the Mississippi Mineral Resources Institute at the University of Mississippi, offered an international workshop entitled "New Concepts in Ocean, Atmosphere, and Seafloor Technologies for Gas Hydrate Investigations and Research" from March 22 to 26, 1999. The program developed at this workshop will monitor outcrops of gas hydrates on the continental slope in the Gulf of Mexico and will use a variety of sensors described in McGee and Woolsey (1999). The workshop included a number of eminent Russian and Canadian hydrate researchers.

Applied Gas Hydrate Research Program (AGHRP)

The MMS is participating through a $5,000 subscription to the AGHRP organized by the Geochemical and Environmental Research Group (GERG) of Texas A&M University. The program is managed by Dr. Roger Sassen, Deputy Director of the Resource Geosciences Division at GERG, and funds an industry/university consortium and associated meetings for one year. Mike Smith, of the MMS Gulf of Mexico OCS Region, represents MMS in consortium activities. Deliverables will include a comprehensive map of hydrate locations developed from over 8,000 piston cores collected over the past 20 years by GERG. The MMS Engineering and Research Branch at Herndon funded this project.

DOE Methane Hydrate Management Steering Committee

The DOE is in the process of securing funds for extensive gas hydrate research. According to the DOE Office of Fossil Energy's report *Strategy for Methane Hydrates Research and Development* (U.S. DOE, 1998a), USGS, National Science Foundation (NSF), Naval Research Laboratory (NRL), and MMS are identified to receive funds to conduct different aspects of the department R&D program. The MMS responded to DOE on June 8, 1998, accepting the invitation to join the methane hydrate Management Steering Committee. Other participants on these committees include the DOE Office of Energy Research, USGS, NRL, NSF, Ocean Drilling Program (ODP), the Natural Gas Supply Association (NGSA), the Gas Research Institute (GRI), and the American Petroleum Institute (API).

4. REVIEW: CURRENT PROGRAMS AND BUDGETS OTHER THAN MMS

Many other groups in the United States and around the world are involved with gas hydrate research. A group of leading U.S. hydrate researchers met at a workshop in February 1999 to review the overall needs of gas hydrate research (Sloan et al., 1999). Representatives from many of the following agencies included here participated in this workshop.

4.1 U.S. Department of Energy (DOE)

In August 1998, the DOE Office of Fossil Energy released *A Strategy for Methane Hydrates Research and Development*, which outlines the foundation for a 10-year science and technology program (U.S. DOE, 1998a). DOE plans to coordinate gas hydrate research activities and provide a foundation for reaching the goal of producing methane from hydrates by the year 2015. This plan is part of DOE's Comprehensive National Energy Strategy (CNES), which defines the Government role as one that will improve the operation of competitive energy markets. The CNES discusses the view that promoting and developing new energy technologies and sources will improve efficiency and reduce some of the negative environmental issues surrounding increased energy usage (U.S. DOE, 1998b).

The DOE focus contains four program goals: (1) to characterize methane hydrates, (2) to produce methane hydrates, (3) to understand the role of methane hydrates in climate change, and (4) to study hazard prevention and the effects of methane hydrates on seafloor stability (U.S. DOE, 1998a).

The DOE also emphasizes that, since the potential to produce methane from gas hydrates on an economic scale is speculative at this point, there is a lack of immediate payoff for R&D spending on production methods for methane hydrates. The DOE advocates enhanced Government funding for hydrate characterization at this early stage, to encourage cooperative efforts and a continued dialogue regarding the potential of this energy source (U.S. DOE, 1998a).

From 1982 to1992, the DOE devoted $8 million to develop a basic understanding of gas hydrates. For FY97 and FY98, modest resources were again devoted to gas hydrates. In FY 99, DOE requested and received $500,000 from Congress for hydrate research and may reprogram other funds for this year. In addition, 5 of the 10 DOE national labs are devoting a combined sum of $1.5 million to hydrates research for FY99. DOE has requested $2 million for FY 2000.

4.2 U.S. Geological Survey (USGS)

The USGS gas hydrate research interests include (1) documenting the geologic parameters that control the occurrence of gas hydrates, (2) improving estimates of natural gas volumes stored as gas hydrates, (3) understanding the effects of gas hydrates on sediment stability, and (4) predicting and preventing geohazards related to gas hydrate production. In 1995, the USGS completed its *National Assessment of United States Oil and Gas Resources*. This was the first study to assess the natural gas hydrate resources of the United States, and it documented that the amount of gas in the hydrate accumulations of the United States greatly exceeds the volume of known conventional domestic gas resources.

Since 1990, USGS has conducted extensive geophysical surveys and established a specialized laboratory facility to model formation and dissociation of oceanic gas hydrates. The USGS continues to study both onshore and offshore hydrate deposits. Gas hydrate distribution in Arctic wells and in the deep sea has been studied extensively by use of geophysical tools and well logs. The USGS has collaborated with several other research groups, including the Ocean Drilling Program (ODP). Most recently, the USGS participated in the cooperative drilling program onshore in the MacKenzie Delta of northern Canada. For the last several years, the USGS has been supporting its gas hydrate research with $700,000 - 800,000 annually.

4.3 Naval Research Laboratory (NRL)

Over the past five years, the NRL has funded gas hydrate research at $500,000 per year. In 1997, the NRL released a report from a September 1997 workshop entitled *Oceanic Gas Hydrate: Guidance for Research and Programmatic Development at the Naval Research Laboratory* (Max et al. 1997). This document outlined the NRL's coordinated interest in learning more about the distribution, properties, chemistry, and influence of gas hydrates on naval operations. The NRL gas hydrate group has been very active in collaborating with other research groups.

The NRL plans to initiate a program to study the dissociation of gas hydrates and the impact of that dissociation on the physical and chemical properties of marine sediments and is budgeting approximately $1 million per year from 2000 through 2004. The agency has worked closely with the DOE in developing the new gas hydrate initiative. While DOE's program centers primarily on developing technology to produce energy from gas hydrates, the NRL program focuses on geoacoustic studies, sediment stability, the relationship between faults, fluid transport, and gas hydrate formation and dissociation.

4.4 Bureau of Land Management (BLM)

The BLM considers gas hydrates to be "non-conventional reservoirs." BLM-Alaska manages the mineral resources in Alaska's North Slope and is interested in becoming involved in discussions about characterization and resource evaluation of gas hydrates, since they are present in this area and other permafrost regions. The BLM does not have a hydrate program in Alaska.

4.5 JOIDES Ocean Drilling Program (ODP)

The ODP is the direct successor to the Deep Sea Drilling Project, (DSDP), which began in 1968 as a U.S. program but quickly evolved into an international effort. The international organization created among the partner countries, Joint Oceanographic Institutions for Deep Earth Sampling (JOIDES), operates as the scientific advisory board for the ODP. Joint Oceanographic Institutions, Inc. (JOI), the prime contractor, subcontracts to Texas A&M University which, as science operator, leases, operates, and staffs the drillship and maintains facilities for storage and study of ODP cores. Lamont-Doherty Geological Observatory of Columbia University is the wire line logging contractor responsible for downhole experiments. This program is funded in part by the National Science Foundation (NSF) and a consortium of 22 countries, including France, West Germany, Japan, the United Kingdom, and Russia.

Several ODP Legs have drilled into gas hydrates, including offshore Guatemala; Blake Ridge, U.S.A.; offshore Central America; Orca Basin, Gulf of Mexico; offshore Peru; offshore western Hokkaido, Japan; Nankai Trough, Japan; and offshore Oregon (Kvenvolden 1995). It was not until 1995, however, that an entire ODP Leg was devoted to gas hydrate research. In the winter of 1995, gas hydrate core samples were taken on Blake Ridge. Results from the cores collected confirmed previous accounts of gas hydrates identified by seismic data and made a major contribution to gas hydrate characterization.

4.6 National Science Foundation (NSF)

The NSF has awarded $750,000 to $1 million in grants per year for the last four years for gas hydrate research. Currently, the NSF has allocated $3 million for projects through 2001. To view current NSF projects, see their web site at http://www.nsf.gov.

4.7 Colorado School of Mines Hydrate Consortium (CSMHC)

The Colorado School of Mines established a Center for Research on Hydrates and other Solids funded at $750,000 per year to pursue hydrate research. Over the last 25 years, 110 gas hydrate publications have been produced by the CSMHC. This program is funded primarily by DOE, NSF, and oil companies. The Deep Star Consortium has also contributed funds. More information on the Colorado School of Mines gas hydrate research is available at http://www.mines.edu/Academic/chemeng.

4.8 Deep Star Consortium

The Deep Star consortium, coordinated by Texaco, has supported 500 studies since 1992 on deepwater production, including gas hydrate prevention technology. Deep Star gas hydrate research focuses on safety and the prevention of gas hydrate formation in flowlines. Along with the DOE, Deep Star is supporting the Rocky Mountain Oil Field test center, a full-scale test center for gas hydrate safety research. The facility simulates four miles of deepwater flowline. Deep Star also supports research on kinetic inhibitors, anti-agglomerates, and other chemicals that prevent gas hydrate formation. Economic production of gas hydrates for energy is not anticipated to be feasible within the planning timeline of Deep Star; therefore, the consortium does not fund that type of work.

4.9 International Gas Hydrate Research, Partnerships, and INTERMAR

The DOE lists the following countries as having active methane hydrate R&D programs: Japan, India, Canada, the United Kingdom, Brazil, Norway, and Russia (U.S. DOE, 1998a). Through the International Activities and Marine Minerals Division (INTERMAR), MMS encourages international cooperation and has memoranda of understanding (MOU's) with several countries. Currently, Japan and India have the most active programs focused on methane recovery.

The Indian government, through the Gas Authority of India Ltd. (GAIL) and the Indian Institute of Technology, began a gas hydrate exploration, technological development, and assessment program in 1996. According to the DOE, India has allocated $56 million for the multi-year program. The Indian Government has also begun a program to offer offshore leases for methane hydrate production. The DOE reports that the Indian Government has shown an interest in collaborating (and funding) work on gas hydrates with the NRL, USGS, DOE, and others.

A draft MOU between MMS and the Indian Directorate General of Hydrocarbons, Ministry of Petroleum and Natural Gas, has been developed to promote cooperation and exchange of information on topics such as regulations and enforcement, resource assessment and economic analysis, data management, leasing management, reserves estimation and management, safety and environmental operations, platform and pipeline abandonment, technology assessment, and training. Unfortunately, work has been halted because of the current sanctions against India by the U.S. Government.

At this time, Japan does not have an MOU with MMS, but collaborative research with the U.S. has occurred in recent years. In 1995, Japan began a program to pursue methane recovery for energy from deposits off the Japanese coast. According to the DOE, Japan is expected to spend about $90 million on hydrates over five years. During February and March of 1998, two holes were drilled into the MacKenzie Delta permafrost to investigate gas hydrates as part of a joint project funded and supported by the USGS, DOE, the Canadian Geologic Survey, and the Japan Petroleum Exploration Co. Ltd. (JAPEX). The Geologic Survey of Japan hydrates web page can be accessed at http://www.aist.go.jp/GSJ/dMG/hydrate/Intro.html.

PART II: MMS Gas Hydrate Information Needs

5. OFFSHORE GAS HYDRATE HAZARDS

Hydrates are a well-known operational hazard that can reduce performance, cause down time, and necessitate expensive remediation. According to the *International Association of Drilling Contractors (IADC) Offshore Operators Committee (OOC) Deepwater Well Control Guidelines* (IADC, 1998), all deepwater drilling operations should have gas hydrate control and relief plans in place before any project begins. For these reasons, MMS is interested in continuing to assist industry by supporting innovative technologies to reduce the problems associated with hydrates.

5.1 What Hazards Are Posed By Hydrates?

Gas hydrates forming in the pipelines can cause extraordinary damage, if they cannot be dislodged by inhibitor injections, heating, depressurization, and/or other methods. If production is stopped, gas hydrates can form on equipment, in lines, and even plug a well. Chemical additives (e.g., methanol, ethylene glycol) can reduce the occurrence of gas hydrates in pipelines (Hudgins 1989). Two newer gas hydrate problem solvers, kinetic inhibitors and anti-agglomerates, have recently become available to industry. Kinetic inhibitors are water soluble polymers that act to slow the formation of hydrates from hours to days. Anti-agglomerates are surfactants that cause hydrates to form in small dispersed crystalline structures instead of as a solid plug. These tools, coupled with proper engineering, advance planning, and awareness of the added risks associated with mitigating production problems in deepwater, provide a sound defense against gas hydrate-related failures in oil and gas production.

The Hydrate Stability Zone (HSZ) intersects the seafloor at about 500 m, and as drilling operations move into deeper waters, the subsea pipelines and platforms will be in zones of hydrate occurrence. Both natural and anthropogenic changes can result in hydrate dissociation, which may trigger seafloor slumps and catastrophic landslides (Dillon, 1999). These slides pose a hazard to conventional oil and gas drilling operations, since a loss of seafloor support affects platforms and pipelines. Drilling and production problems attributed to the presence of gas hydrates include uncontrolled gas releases during drilling, collapse of wellbore casings, and gas leakage to the surface around the outside of the wellbore, which may result in local seafloor subsidence and the loss of support for foundations of drilling platforms (Dillon, 1999). It is speculated that the drilling itself may cause the dissociation of gas hydrate, since warm drilling fluids and/or the production of hot hydrocarbons from below can cause the gas hydrates in the sediments to destabilize (Dillon, 1999).

5.2 Gas Hydrates in the MMS Permitting Process

As outlined above, gas hydrates can pose a variety of hazards at various stages of oil and gas production. The first time that gas hydrates are addressed in the MMS permitting process occurs when a company submits a Plan of Exploration (POE) to the Office of Field Operations. If the company identifies potential gas hydrate outcrops in the lease area, the company generally plans to avoid disturbing them. The MMS requires avoidance if chemosynthetic communities, which are associated with the hydrate deposits, are identified. When the POE is submitted to the MMS, geoscientists evaluate the locations of gas hydrates and notify the company of any discrepancies in the identification of hydrates. After the surface location is approved, the company submits an Application for Permit to Drill (APD). Gas hydrates are avoided in the locations defined in the APD. In the Gulf of Mexico, gas hydrates are usually localized, and gas vents and oil seeps can be identified. So far, companies have voluntarily avoided hydrate areas and, to date, no hydrate-related accidents have occurred during drilling in U.S. waters.

Currently, the MMS is suggesting changes to 30 CFR 250 that will require industry to submit more geological and geophysical information during the surface site selection process to aid in the identification of gas hydrates and other shallow hazards. Shallow seismic data can be loaded in a 16- or 32-bit format to map shallow amplitudes associated with gas hydrates accurately. These suggestions were presented at the 1999 Offshore Technology Conference in Houston, Texas (Stauffer, et al. 1999) and incorporated as the new basis of the MMS Notice to Lessees and Operators (NTL) on shallow geohazards in the Gulf of Mexico OCS (NTL-98-20).

5.3 Gas Hydrates in MMS Pipeline Regulations

Before pipelines are set on the seafloor, industry must submit plans to MMS for approval. The MMS currently does not require industry to address pipeline blockage problems and remediation strategies in the pipeline plans. The MMS views methane hydrates as a performance issue and recognizes that having a hydrate mitigation plan is in the company's best interest. Oil and gas companies must design and operate pipelines to withstand certain environmental conditions, and one of these is the risk of gas hydrate formation. As a result, MMS has seen an increase of pipe-in-pipe installations to allow for the use of insulating material in the annular spaces between pipes. In addition, industry has started to bury pipelines in deeper waters for insulation, industry monitors the water content of the product, and establishes injection programs to add chemical gas hydrate inhibitors where needed.

Before a pipeline is laid in areas of rough terrain or unstable slopes, such as the ones encountered in deepwater, a pipeline hazards (seabed) survey is conducted using an ROV (remotely operated vehicle), before and after installation, to confirm sea bottom conditions visually. The pipeline route is altered to avoid areas where hydrates or other hazards are identified.

5.4 Industry and Academia Perspective on Gas Hydrates as Geohazards

Some researchers are less confident that current industry practices will prevent a gas hydrate-related accident in the Gulf of Mexico. The primary hydrate issue at the present time is hazards. The hazards of greatest concern include drilling difficulties caused by sediments that may contain hydrates, hydrate blockages stretching for up to 1 km inside pipes, pressure buildup inside pipes, the risk of blowouts, and seafloor stability issues for equipment/pipelines. Dr. Sassen of Texas A&M University submitted a letter outlining his perspective on gas hydrate hazards (Appendix 2).

The MMS believes that, in general, the oil and gas industry is doing a good job of screening for hydrates and taking preventative measures. The MMS and industry work together to ensure that safety is integral to the approval process to drill and, therefore, MMS may not need to alter the permitting procedures to require strict, specific gas hydrates safety measures. This collaborative effort is promising. Industry is particularly committed to maintaining an exchange of information with MMS on safety issues.

5.5 Gas Hydrates Along the West Coast and Alaska

Methane hydrates off the coast of the U.S. have been most extensively studied along Blake Ridge off South Carolina and in the Gulf of Mexico. Hydrates also occur along the west coast and Alaska. According to the USGS (Figure 3), the largest deposits are estimated to exist in these two areas, especially Alaska, with greater than 50 percent of the estimated resource. A recent presentation at the American Geophysical Union 1999 spring meeting discussed the wide distribution of gas hydrates off the coast of Oregon (Trehu et al., 1999).

In the North Slope area of onshore Alaska (north of the Brooks Range), gas hydrate accumulations are associated with the base of the permafrost layer. The permafrost can range up to 1,000 to 2000 feet thick onshore and can extend offshore in a gradually thinning layer to areas under up to 90 meters of water. Present USGS in-place resource estimates for permafrost-related gas hydrates on the North Slope and permafrost-related and shelf-edge "marine" gas hydrates in the associated offshore EEZ total up to 600 TCF. About 45 TCF of this is located in the West Prudhoe Bay and Kuparuk River areas. Amounts exceeding the West Prudhoe Bay reserves may be present over the Tarn oil field area to the southwest of Prudhoe Bay.

The possibility of producing gas from gas hydrates over the Milne Point Field northwest of Prudhoe Bay for reinjection and field pressure maintenance is now under evaluation. If production of the gas is technically feasible, this production represents savings over imported gas and extends the life of the field. Gas hydrates at Milne Point have been shown to extend offshore to the north and northwest on seismic lines, possibly continuing onto OCS lands.

Potential marine-derived gas hydrates are indicated by the presence of BSR's more than 100 km offshore north of Alaska at depths greater than 250 to 300 m. This is well offshore from any drilling thus far or contemplated in the area.

Beyond this geologic background information, we must also point out that conventional gas production in the northern Alaska OCS is projected to be noneconomic for many years. Under present conditions, gas prices would have to be in the range of $8.00/MCF before there would be any consideration of OCS gas production in the area. Given this constraint, it seems unlikely that there will be any effort made to exploit technically and economically risky OCS gas hydrate deposits in the area in the foreseeable future.

6. METHANE HYDRATE ENVIRONMENTAL CONCERNS

Just as the interest in producing gas hydrates for energy continues to increase, the list of environmental concerns continues to grow. At present, researchers consider gas hydrates to play a role in climate change, oil spill plume behavior, and the existence of ocean floor biological communities. If hydrate production becomes a reality, a major concern for MMS and others will be how to evaluate the potential impacts on marine life by oceanic methane hydrate production methods.

6.1 Methane Hydrates and Climate Change

One of the main reasons that methane hydrates are appearing in the scientific literature at present is their possible involvement in climate change. Researchers argue that increases in the concentration of atmospheric greenhouse gases, such as methane and carbon dioxide, will result in increases in the amount of heat retained by the Earth's atmosphere. Methane is both sequestered and released by methane hydrates, depending on the pressure and temperature conditions. There is evidence to suggest that destabilized gas hydrates can induce landslides and seafloor subsidence, and thereby release large volumes of methane into the atmosphere (Paull et al., 1991 and Dillon et al., 1998). However, mechanisms of release and the relationships between sea level, pressure changes due to sedimentation, ocean temperature, hydrate dissociation, and the frequency of methane release events have yet to be characterized (Dillon et al., 1998).

Whether or not the contribution of methane released from gas hydrates now and in the past is large enough to affect global climate is debatable. Kvenvolden (1988) concludes that the amount of methane being released at present is probably not large and will not contribute significantly to the global warming phenomenon. Paull et al. (1991), however, proposes a larger role for hydrates in climate change by suggesting that methane originating from offshore hydrates may be released to the atmosphere in large "spikes," which may have played a role in limiting past glacier advances. Max and Lowrie (1996) question how much methane released from hydrates would actually reach the atmosphere, since a significant portion may dissolve in seawater or be oxidized by the sulfates immediately after release.

An alternate role of gas hydrates in climate change is as a method of sequestering carbon dioxide. Recently, experiments were conducted off the coast of California in which carbon dioxide was pumped to the seafloor (Monastersky, 1999). Balls of gas hydrate were formed, trapping the greenhouse gas deep in the ocean. Plans are underway to inject 50 to 100 tons of liquid carbon dioxide into waters off Kona, Hawaii.

6.2 Natural Gas: The "Green" Fuel of Choice

Another facet of the climate change debate is that natural gas is considered to be a "clean fuel." Methane produces less carbon dioxide per unit of energy than other fossil fuels. It is estimated that use of methane could reduce carbon dioxide emissions by as much as 20 percent on a global basis. Therefore, should the United States choose to make extensive commitments to reduce carbon dioxide emissions, the expanded use of natural gas is expected to play a large role in meeting emission goals (Kripowicz, 1999).

6.3 Chemical Additives

If a gas hydrate plug forms in a pipeline, then injecting a chemical inhibitor, such as methanol or ethylene glycol, is often the first remediation method available (Hudgins, 1989 and IADC, 1998). When water is detected in the product, the inhibitor is usually injected continuously in the pipe to prevent hydrates from forming in the system until the water can be removed (Hudgins, 1989). Both the MMS and EPA are interested in keeping track of what chemicals are being used to keep lines clear of hydrates and how they are disposed of after use, though neither agency has a specific regulatory program for the disposal of chemicals used in offshore production. The MMS recently initiated a literature review, Environmental Risks of Chemical Products Used in Deepwater Oil and Gas Operations, in an effort to catalog the different products in use. This study is expected to generate a list of chemicals commonly used for production, including ones used to inhibit gas hydrate formation. This effort is also intended to help MMS engineers and scientists model the risks associated with a chemical spill. At this point, MMS is monitoring chemical use associated with deepwater activities.

Another set of chemicals that relate to methane hydrates are synthetic drilling fluids. Since hydrates can form in the drilling “muds” necessary for well drilling, some operators have opted to use synthetic drilling fluids that can improve performance in part by reducing the probability of gas hydrate formation (Friedheim, 1997).

6.4 Oil Spill Plume Behavior and Gas Hydrates

When oil is released in deepwater, gas hydrate formation can alter the behavior of the spill. Gas hydrates can create a buoyant plume of gas, oil, and hydrates. To respond to the behavior of a deepwater spill, it is necessary to consider how the presence of hydrates may alter the plume behavior. Modeling efforts suggest that these plumes can “mushroom,” rise, and disperse horizontally, though more work needs to be completed. The MMS co-sponsored a workshop on oil spill plume behavior in February 1999, which included this issue.

The MMS research programs (Environmental Studies and Technology Assessment) have joined, together with industry, a Deep Spills Task Force. The task force has already begun a numerical modeling study of plume dynamics and laboratory studies of various aspects of the problem, including the formation of hydrates during a deep spill blowout or pipeline leak. A field experiment is planned for June 2000, off the coast of Norway at 1000 meter depth, in which oil and gas will be released and monitored for hydrate formation and plume characterization.

6.5 Protecting Chemosynthetic Communities

The MMS has funded two large scale studies on the chemosynthetic communities that thrive, in part, on methane hydrates in the Gulf of Mexico. The study, *Northern Gulf of Mexico Continental Slope Chemosynthetic Communities Program*, was completed in 1995 (MacDonald et al., 1995). An ongoing project, Stability and Change in Gulf of Mexico Chemosynthetic Communities, was initiated in 1995. These two projects together span a decade, 1991-2001.

The first study included a literature review and an examination of the regional distribution of chemosynthetic communities across the continental slope in the northern Gulf and the geologic and geophysical characterization of associated hydrocarbon deposits, including gas hydrates. It described the ages of the habitats and the general ecology of the chemosynthetic communities thriving on gas hydrates near oil and gas seeps.

The ongoing study is designed to provide MMS with the information necessary to manage these sensitive biologic communities effectively. This study will provide an understanding of the processes that control the distribution, health, and succession of these communities and the effects of oil and gas exploration, including gas hydrate disturbance, on these communities. At the regional level, this effort is focusing on the geological, chemical, and oceanographic processes that maintain the stability of these communities.

6.6 Environmental Effects of Proposed Methane Hydrate Production Methods

If plans are ever submitted to produce methane from offshore hydrates, MMS will need to develop an environmental assessment (EA) or possibly an environmental impact statement (EIS). Extraction of methane hydrates from the seafloor could lead to subsidence. A deeper understanding of the geological setting and the effects of the removal of hydrate is needed before production can begin (Max and Cruickshank, 1999). The regulations in place that govern conventional oil and gas may not apply to methane hydrates. The MMS will need to make the assessments and modify the regulations before the start of production. S. 330 proposes a commercial demonstration will be in operation by 2015. In Alaska, the permafrost hydrate resource, which may be the first to be developed, needs to be investigated.

7. METHANE HYDRATES AS AN ENERGY RESOURCE

7.1 The Role of Natural Gas

According to current estimates of methane hydrate resources, gas hydrates contain more fossil fuel energy than any other source (Figure 1; Kvenvolden, 1993). Many research groups, both public and private, are starting to solve the technical and economic problems associated with tapping methane hydrates as an energy resource.

The DOE notes in *A Strategy for Methane Hydrates Research and Development* that the role of natural gas in U.S. power generation is expected to increase because of the pressure to use cleaner fuels and the relatively low costs required to build natural gas-fired/combined cycle power plants (U.S. DOE, 1998a). In addition, natural gas is also being tested as a transportation fuel and as a potential source of alternative liquid fuels from gas-to-liquids conversion (U.S. DOE, 1998a). It is anticipated that the national demand for natural gas will reach 30 TCF by the year 2010. Production of gas hydrates will be encouraged by this and eventually may well help to meet this need.

7.2 Industry and Academia Perspective on Methane Hydrate Production

Though methane hydrates are not a priority for research spending, U.S. industry is paying attention to advances in hydrate production technology and the agendas of international research groups actively trying to produce hydrates. In the past, industry considered methane hydrate production highly improbable, but today some industry groups are reconsidering their approach (U.S. DOE 1998a). While there is much to learn, industry now recognizes the potential of gas hydrates and supports the DOE's ambitious plan to produce gas hydrates by 2015.

While industry does understand the potential for energy of gas hydrates, some suggest that the timeline for producing hydrates extends far into the future. At this time, funds devoted by industry for gas hydrate research are dedicated primarily to hazard prevention. Industry considers gas hydrate production to be beyond the planning scope of their current R & D plans. Therefore, little money is being earmarked by U.S. industry for advances in gas hydrate production technology.

Regardless of the interest, hazard prevention or energy production, additional work needs to be completed to characterize and locate gas hydrate deposits. By collecting drill core data, the hydrate stability zone can be better related to seismic data. The hydrate stability zone is a moving target, especially near the seafloor. Changes in water temperature at the seafloor can significantly change where the shallow hydrate stability zone exists. In addition, at depth the geothermal gradient affects the lower boundary of the stability zone. After the gradients are known and mapped, then the ability to pinpoint and predict occurrences of gas hydrates will be simplified. According to Arthur Johnson (Personal comm., 1999), this will benefit all future gas hydrate endeavors. Questions remain, however, as to who will do the work, when it will be completed, and how it will be funded.

7.3 Methane Hydrate Production Methods

The oil and gas industry has not yet developed economically viable methodologies to release methane from hydrates by using significantly less energy than the amount of thermal energy recovered in the form of methane (Kvenvolden, 1998, Max and Cruickshank, 1999). Several methods for gas recovery from hydrates have been tested, including (1) injecting methanol, or another inhibitor, into the reservoir to decrease hydrate stability; (2) heating the gas hydrates above the maximum temperature of the hydrate stability zone (HSZ); and (3) decreasing the reservoir pressure below the minimum pressure of the HSZ (Max and Cruickshank, 1999). Gas hydrates have already been commercially produced from the Messoyakha gas field in western Siberia, where natural gas was first detected in permafrost in 1970 (Makogan et al., 1972). According to Kvenvolden (1998), initially the methane was produced at Messoyakha by using methanol injection. This proved, however, to be too expensive for commercial production. Currently, depressurization is being used at the Messoyakha gas field (Max and Lowrie, 1996). Chemical inhibitors were also used to produce methane from gas hydrates in the Prudhoe Bay-Kuparuk River gas field in Alaska (Malone, 1990).

According to Dillon (1999), computer models suggest that methane can be produced from hydrates at fast enough rates from hot water and steam injection to make gas hydrate recovery a viable option. Max and Lowrie (1996) argue, however, that while this method has been used onshore in permafrost regions, it may not be appropriate for offshore operations because of the heat required. The most promising method to date for offshore gas hydrate operations probably is depressurization. The pressure inside a free gas pocket below a gas hydrate deposit can be controlled as a function of the gas extraction (Max and Lowrie, 1996). For oceanic deposits, the pressure in the reservoirs would have to be lowered significantly to extract the methane. Max and Lowrie (1996) assert that the hydrates that contact lower pressure gas would also destabilize and convert to gas for extraction.

One hindrance for the development of economically attractive production methods for offshore gas hydrates is that they are often widely dispersed (Dillon, 1999). In fact, determining the existence of gas hydrates is more complicated in the Gulf of Mexico than in some other offshore locations such as Blake Ridge, which has distinct bottom simulating reflectors (BSR) for easy gas hydrate detection (Roberts et al., 1999). The Gulf of Mexico has a complex geologic layout because of the massive influxes of sediment from the Mississippi River and salt tectonics (Roberts et al., 1999 and Johnson, 1999). This geologic history, which gives rise to an intricate array of faulting, fluid and gas releases, salt masses, and complex temperature and pressure zones, can confound BSR readings. In the Gulf of Mexico, drill core samples are especially needed to characterize gas hydrate deposit locations and behaviors before any kind of production is attempted.

7.4 Methane Hydrate Included in Lease Agreements

In a June 2, 1998, letter to Chevron U.S.A. Production Company, the MMS Associate Director for Offshore Minerals Management stated:

> "The OCS Lands Act authorizes MMS to manage OCS mineral resources. Therefore, MMS is authorized to manage any future development of gas hydrates. A company has the rights to produce gas from hydrates and any free gas that is below the solid gas hydrate phase on its OCS oil and gas leases."

This letter was approved by the Department of the Interior Solicitor's Office, and the Bureau of Land Management (BLM) concurs with the MMS's decision to allow hydrates to be included as part of OCS leases. Hydrates extracted from permafrost would be included in leases managed by BLM, and are not within the jurisdiction of MMS.

7.5 Mapping Gas Hydrates

The MMS Gulf of Mexico OCS Region recently completed a study, Gulf of Mexico Bottom Seismic Amplitude and Bathymetry Study. The objectives of this study are five-fold: (1) to characterize geologic trends, including faults, and faulted salt diapirs, that show anomalous amplitude responses; (2) to map the amplitude responses of known chemosynthetic communities; (3) to determine if mapping seismic data can help identify hydrocarbon reservoirs at depth; (4) to determine if identified amplitude anomalies can help with risk assessment; and (5) to serve as an initial step in quality assurance when new 3-D seismic surveys are received.

The results of the study include (1) water bottom amplitude and bathymetry maps for each 3-D seismic survey in the deepwater Western and Central Gulf of Mexico, (2) representative lines demonstrating anomalies in each survey area, (3) a gulf-wide index map showing all current 3-D surveys, (4) water bottom map files in an accessible ArcView format, and (5) an outline of all methods used for the project. When new data on gas hydrates or other features are made available, the newly available data can be quickly added to the central database. This database will include data from ~1,200 ocean floor core samples, some of which contain evidence of gas hydrates, and data on more than 20 pressurized gas hydrate cores sampled by Texas A&M researchers (Figure 5).

Through this study, MMS can correlate bottom amplitude anomalies with chemosynthetic communities, gas hydrates, and known oil and gas production areas. Improvements in methods to identify chemosynthetic communities will help MMS and the oil industry minimize the environmental disruption of these delicate communities. Improvements in identifying gas hydrates would have many applications for safety, resource evaluation, and possible future resource recovery. In general, if relationships between production fault trends and certain anomalies can be assessed, then the assessment of geologic risk for oil and gas prospects being evaluated for fair market value is expected to improve.

7.6 MMS: The Manager of U.S Offshore Gas Hydrates

As the manager of offshore leases, MMS will eventually be responsible for developing any regulatory guidelines addressing the recovery of methane hydrates. Therefore, MMS is monitoring the development of research and management programs discussed above. Early involvement will ensure that MMS has the necessary information to prepare environmental assessments, make resource evaluations, and identify OCS safety concerns. There are several environmental issues to consider before development. First, there may be a major disruption of large areas of the sea floor because of reduced bottom stability, resulting in possible landslides. Second, there is the question of the effect on the surface and near-surface biological communities from a substantial flow of methane and other associated gases through their habitat. Third, there is a likelihood that among those associated gases are poisonous gases such as hydrogen sulfide.

In addition, since MMS has access to a vast body of both proprietary and publicly available seismic and well data, it is in a unique position to determine where the offshore hydrates are located. One challenge for MMS is to decide, since all of the information is proprietary, how and on what scale to make some of these data available.

8. PROPOSED RECOMMENDATIONS

Overall, the MMS should continue to support gas hydrate activities when these meet the objectives of the MMS Outer Continental Shelf oil and gas program.

8.1 Short-term Issues

- Gas hydrate formation is a nuisance during oil and gas exploration and production activities. Industry is very involved in addressing this issue, including the formation of hydrates on equipment and in flowlines. Engineering designs and the use of chemical flowline enhancers are used to address this problem.

- Gas hydrates as a geohazard pose a safety concern. At present, oil companies avoid areas with suspected hydrate deposits, at least in the Gulf of Mexico. Increased understanding about the location and distribution could add to the margin of safety already practiced.

- The ongoing geophysical sea floor mapping program being undertaken by RE staff is revealing a positive correlation between surface anomalies, fault patterns, and known hydrocarbon sources. This information may be used to interpret seismic data when evaluating surface outcrops of methane hydrates and associated chemosynthetic communities, but a lack of groundtruthing prevents a definitive interpretation. A sampling program of known sites, including characterization of the geophysical signature of normal, soft bottom muds, as well as the hydrate/chemosynthetic sites, is critical to MMS's ability to accurately interpret seismic anomaly data with confidence.

- The MMS is a repository for an extensive body of data relating to the location and characteristics of gas hydrates. Therefore, MMS may want to develop an appropriate mechanism for sharing this information with industry and research groups in the future.

- Gas hydrates may be used to evaluate geologic risk for oil and gas prospects. The MMS should continue to update its Gulfwide mapping project database with data from current and future gas hydrate drilling projects and seismic data.

- The MMS should continue to participate in gas hydrate consortiums and develop gas hydrate research agendas with outside groups. Many programs are already underway or are being developed; they will yield important information for making future assessments and modifying regulations.

8.2 Long-term Issues

- Gas hydrate extraction may become a reality as soon as 2015. The MMS should monitor the progress of hydrate resource development and prepare accordingly for the ramifications of the development of this resource, including regulations governing technology and safety, environmental assessments of impacts, and resource evaluation for royalty determinations.

9. ACKNOWLEDGMENTS

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APPENDIX 1

U.S. Senate Bill S330
and
Testimony from Gas Hydrate Experts before the U.S. Senate,
September 15, 1998

Methane Hydrate Research and Development Act of 1999 (Introduced in the Senate)

S 330 IS

106th CONGRESS

1st Session

S. 330

To promote the research, identification, assessment, exploration, and development of methane hydrate resources, and for other purposes.

IN THE SENATE OF THE UNITED STATES

January 28, 1999

Mr. AKAKA (for himself, Mr. LOTT, Ms. LANDRIEU, Mr. CRAIG, and Mr. GRAHAM) introduced the following bill; which was read twice and referred to the Committee on Energy and Natural Resources

A BILL

To promote the research, identification, assessment, exploration, and development of methane hydrate resources, and for other purposes.

Be it enacted by the Senate and House of Representatives of the United States of America in Congress assembled,

SECTION 1. SHORT TITLE.

This Act may be cited as the `Methane Hydrate Research and Development Act of 1999'.

SEC. 2. DEFINITIONS.

In this Act:

(1) CONTRACT - The term `contract' means a procurement contract within the meaning of section 6303 of title 31, United States Code.

(2) COOPERATIVE AGREEMENT - The term `cooperative agreement' means a cooperative agreement within the meaning of section 6305 of title 31, United States Code.

(3) GRANT - The term `grant' means a grant awarded under a grant agreement, within the meaning of section 6304 of title 31, United States Code.

(4) INSTITUTION OF HIGHER EDUCATION - The term `institution of higher education' means an institution of higher education, within the meaning of section 102(a)(1) of the Higher Education Act of 1965.

(5) METHANE HYDRATE - The term `methane hydrate' means a methane clathrate that--

(A) is in the form of a methane-water ice-like crystalline material; and

(B) is stable and occurs naturally in deep-ocean and permafrost areas.

(6) SECRETARY - The term `Secretary' means the Secretary of Energy.

(7) SECRETARY OF DEFENSE - The term `Secretary of Defense' means the Secretary of Defense, acting through the Secretary of the Navy.

(8) SECRETARY OF THE INTERIOR - The term `Secretary of the Interior' means the Secretary of the Interior, acting through the Director of the United States Geological Survey.

(9) DIRECTOR - The term `Director' means the Director of the National Science Foundation.

SEC. 3. METHANE HYDRATE RESEARCH AND DEVELOPMENT PROGRAM.

(a) IN GENERAL -

(1) COMMENCEMENT OF PROGRAM - Not later than 180 days after the date of enactment of this Act, the Secretary, in consultation with the Secretary of Defense, the Secretary of the Interior, and the Director, shall commence a program of methane hydrate research and development.

(2) DESIGNATIONS- The Secretary, the Secretary of Defense, the Secretary of the Interior, and the Director shall designate individuals to carry out this section.

(3) MEETINGS- The individuals designated under paragraph (2) shall meet not later than 120 days after the date on which all such individuals are designated and not less frequently than every 120 days thereafter to--

(A) review the progress of the program under paragraph (1); and

(B) make recommendations on future activities to occur subsequent to the meeting.

(b) GRANTS, CONTRACTS, AND COOPERATIVE AGREEMENTS-

(1) ASSISTANCE AND COORDINATION- The Secretary may award grants or contracts to, or enter into cooperative agreements with, institutions of higher education and industrial enterprises to--

(A) conduct basic and applied research to identify, explore, assess, and develop methane hydrate as a source of energy;

(B) assist in developing technologies required for efficient and environmentally sound development of methane hydrate resources;

(C) undertake research programs to provide safe means of transport and storage of methane produced from methane hydrates;

(D) promote education and training in methane hydrate resource research and resource development;

(E) conduct basic and applied research to assess and mitigate the environmental impacts of hydrate degassing (including both natural degassing and degassing associated with commercial development); and

(F) develop technologies to reduce the risks of drilling through methane hydrates.

(2) CONSULTATION- The Secretary may establish an advisory panel consisting of experts from industry, institutions of higher education, and Federal agencies to--

(A) advise the Secretary on potential applications of methane hydrate; and

(B) assist in developing recommendations and priorities for the methane hydrate research and development program carried out under subsection (a)(1).

(C) LIMITATIONS—

(1) ADMINISTRATIVE EXPENSES- Not more than 5 percent of the amount made available to carry out this section for a fiscal year may be used by the Secretary for expenses associated with the administration of the program carried out under subsection (a)(1).

(2) CONSTRUCTION COSTS- None of the funds made available to carry out this section may be used for the construction of a new building or the acquisition, expansion, remodeling, or alteration of an existing building (including site grading and improvement and architect fees).

(D) RESPONSIBILITIES OF THE SECRETARY- In carrying out subsection (b)(1), the Secretary shall--

(1) facilitate and develop partnerships among government, industry, and institutions of higher education to research, identify, assess, and explore methane hydrate resources;

(2) undertake programs to develop basic information necessary for promoting long-term interest in methane hydrate resources as an energy source;

(3) ensure that the data and information developed through the program are accessible and widely disseminated as needed and appropriate;

(4) promote cooperation among agencies that are developing technologies that may hold promise for methane hydrate resource development; and

(5) report annually to Congress on accomplishments under this section.

SEC. 4. AMENDMENT TO THE MINING AND MINERALS POLICY ACT OF 1970.

Section 201 of the Mining and Minerals Policy Act of 1970 (30 U.S.C. 1901) is amended--

(1) by redesignating paragraphs (6) and (7) as paragraphs (7) and (8), respectively;

(2) by inserting after paragraph (5) the following:

(6) The term `methane hydrate' means a methane clathrate that--

(A) is in the form of a methane-water ice-like crystalline material; and

(B) is stable and occurs naturally in deep-ocean and permafrost areas.; and

(3) in paragraph (7) (as redesignated by paragraph (1))--

(A) in subparagraph (F), by striking `and' at the end;

(B) by redesignating subparagraph (G) as subparagraph (H); and

(C) by inserting after subparagraph (F) the following:

(G) methane hydrate; and'.

SEC. 5. AUTHORIZATION OF APPROPRIATIONS.

There are authorized to be appropriated such sums as are necessary to carry out this Act.

Statement of
William P. Dillon
Research Geologist
U.S. Geological Survey
Before the
U.S. House of Representatives
Committee on Science
Subcommittee on Energy and Environment
Hearing on S. 1418
the Methane Hydrate Research and Development Act of 1997
Rayburn House Office Building, Room 2318
Washington, D.C.
September 15, 1998

Mr. Chairman and Members:

I am William P. Dillon, Research Geologist with the U.S. Geological Survey (USGS). In this testimony I will discuss the USGS assessment of natural gas hydrate resources and examine the technology that would be necessary to safely and economically produce gas hydrates.

I. Summary

The primary objectives of USGS gas hydrate research are to document the geologic parameters that control the occurrence and stability of gas hydrates, to assess the volume of natural gas stored within gas hydrate accumulations, to identify and predict natural sediment destabilization caused by gas hydrate, and to analyze the effects of gas hydrate on drilling safety. The USGS in 1995 made the first systematic assessment of the in-place natural gas hydrate resources of the United States. That study shows that the amount of gas in the hydrate accumulations of the United States greatly exceeds the volume of known conventional domestic gas resources. However, gas hydrates represent both a scientific and technologic frontier and much remains to be learned about their characteristics and possible economic recovery.

II. Gas Hydrate Occurrence and Characterization

Gas hydrates are naturally occurring crystalline substances composed of water and gas, in which a solid water-lattice holds gas molecules in a cage-like structure. Gas hydrates are widespread in permafrost regions and beneath the sea in sediments of the outer continental margins. While methane, propane, and other gases are included in the hydrate structure, methane hydrates appear to be the most common. The amount of methane contained in the world's gas hydrate accumulations is enormous, but estimates of the amounts are speculative and range over three orders-of-magnitude from about 100,000 to 270,000,000 trillion cubic feet of gas. Despite the enormous range of these estimates, gas hydrates seem to be a much greater resource of natural gas than conventional accumulations.

Even though gas hydrates are known to occur in numerous marine and Arctic settings, little is known about the geologic controls on their distribution. The presence of gas hydrates in offshore continental margins has been inferred mainly from anomalous seismic reflectors that coincide with the base of the gas-hydrate stability zone. This reflector is commonly called a bottom simulating reflector or BSR. BSRs have been mapped at depths ranging from about 0 to 1,100 in below the sea floor. Gas hydrates have been recovered by scientific drilling along the Atlantic, Gulf of Mexico, and Pacific coasts of the United States, as well as at many international locations.

To date, onshore gas hydrates have been found in Arctic regions of permafrost and in deep lakes such as Lake Baikal in Russia. Gas hydrates associated with permafrost have been documented on the North Slope of Alaska and Canada and in northern Russia. Direct evidence for gas hydrates on the North Slope of Alaska comes from cores and petroleum industry well logs which suggest the presence of numerous gas hydrate layers in the area of the Prudhoe Bay and Kuparuk River oil fields. Combined information from Arctic gas-hydrate studies shows that, in permafrost regions, gas hydrates may exist at subsurface depths ranging from about 130 to 2,000 meters.

The USGS 1995 National Assessment of United States Oil and Gas Resources 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 appraisal of the in-place natural gas hydrate resources of the United States, both onshore and offshore. Eleven gas-hydrate plays were identified within four offshore and one onshore gas hydrate provinces. The offshore provinces lie within the U.S. 200 mile Exclusive Economic Zone adjacent to the lower 48 States and Alaska. The only onshore province assessed was the North Slope of Alaska. In-place gas hydrate resources of the United States are estimated to range from 113,000 to 676,000 trillion cubic feet of gas, at the 0.95 and 0.05 probability levels, respectively. Although this range of values shows a high degree of uncertainty, it does indicate the potential for enormous quantities of gas stored as gas hydrates. The mean (expected value) in-place gas hydrate resource for the entire United States is estimated to be 320,000 trillion cubic feet of gas. This assessment does not address the problem of gas hydrate recoverability.

Seismic-acoustic imaging to identify gas hydrate and its effects on sediment stability has been an important part of USGS marine studies since 1990. USGS has also conducted extensive geophysical surveys and established a specialized laboratory facility to study the formation and disassociation of gas hydrate in nature and also under simulated deep-sea conditions. Gas hydrate distribution in Arctic wells and in the deep sea has been studied intensively using geophysical well logs. These efforts have also involved core drilling of gas-hydrate-bearing sediments in cooperation with the Ocean Drilling Program (ODP) of the National Science Foundation, and, most recently a cooperative drilling program onshore in northern Canada.

III. Gas Hydrate Production

Gas recovery from hydrates is hindered because the gas is in a solid form and because hydrates are usually widely dispersed in hostile Arctic and deep marine environments. Proposed methods of gas recovery from hydrates usually deal with disassociating or "melting" in-situ gas hydrates by (1) heating the reservoir beyond the temperature of hydrate formation, (2) decreasing the reservoir pressure below hydrate equilibrium, or (3) injecting an inhibitor, such as methanol, into the reservoir to decrease hydrate stability conditions. Computer models have been developed to evaluate hydrate gas production from hot water and steam injection, and these models suggest that gas can be produced from hydrates at sufficient rates to make gas hydrates a technically recoverable resource. Similarly, the use of gas hydrate inhibitors in the production of gas from hydrates has been shown to be technically feasible, however, the use of large volumes of chemicals comes with a high economic and potential environmental cost. Among the various techniques for production of natural gas from in-situ gas hydrates, the most economically promising method is considered to be depressurization. The Messoyakha gas field in northern Russia is often used as an example of a hydrocarbon accumulation from which gas has been produced from hydrates by simple reservoir depressurization. Moreover the production history of the Messoyakha field possibly demonstrates that gas hydrates are an immediate producible source of natural gas and that production can be started and maintained by "conventional" methods.

IV. Safety and Seafloor Stability

Seafloor stability and safety are two important issues related to gas hydrates. Seafloor stability refers to the susceptibility of the seafloor to collapse and slide as the result of gas hydrate disassociation. The safety issue refers to petroleum drilling and production hazards that may occur in association with gas hydrates in both offshore and onshore environments.

Seafloor Stability

Along most ocean margins the depth to the base of the gas hydrate stability zone becomes shallower as water depth decreases; the base of the stability zone intersects the seafloor at about 500 m. It is possible that both natural and human induced changes can contribute to in-situ gas hydrate destabilization which may convert a hydrate-bearing sediment to a gassy water-rich fluid, triggering seafloor subsidence and catastrophic landslides. Evidence implicating gas hydrates in triggering seafloor landslides has been found along the Atlantic Ocean margin of the United States. The mechanisms controlling gas hydrate induced seafloor subsidence and landslides are not well known, however these processes may release large volumes of methane to the Earth's oceans and atmosphere.

Safety

Throughout the world, oil and gas drilling is moving into regions where safety problems related to gas hydrates may be anticipated. Oil and gas operators have described numerous drilling and production problems attributed to the presence of gas hydrates, including uncontrolled gas releases during drilling, collapse of wellbore casings, and gas leakage to the surface. In the marine environment, gas leakage to the surface around the outside of the wellbore casing may result in local seafloor subsidence and the loss of support for foundations of drilling platforms. These problems are generally caused by the disassociation of gas hydrate due to heating by either warm drilling fluids or from the production of hot hydrocarbons from depth during conventional oil and gas production. The same problems of destabilized gas hydrates by warming and loss of seafloor support may also affect subsea pipelines.

V. Conclusions

Our knowledge of naturally occurring gas hydrates is limited. Nevertheless, a growing body of evidence suggests that (1) a huge volume of natural gas is stored in gas hydrates, (2) production of natural gas from gas hydrates may be technically feasible, (3) gas hydrates hold the potential for natural hazards associated with seafloor stability and release of methane to the oceans and atmosphere, and (4) gas hydrates disturbed during drilling and petroleum production pose a potential safety problem. The USGS welcomes the opportunity to collaborate with domestic and international scientific organizations to further our collective understanding of these important geologic materials.

William P. Dillon

William P. Dillon is a research geologist in the Geologic Division of the U.S. Geological Survey (USGS). He has served at the USGS Coastal and Marine Research Centers in both Woods Hole, MA and Menlo Park, CA and is currently project chief of the USGS gas hydrate research effort in the Coastal and Marine Program. Dillon holds a B.S. from Bates College, a M.S. from Rensselaer Polytechnic Institute, and a Ph.D. from the University of Rhode Island. Before joining the U.S. Geological Survey in 1971, he was a professor in oceanography at San Jose State University and on the staff of the University of Rhode Island.

Testimony of
Arthur H. Johnson
Senior Staff Geologist
Chevron USA Production Company
to the
U.S. House of Representatives
Committee on Science
Subcommittee on Energy and Environment
Hearing on S. 1418
the Methane Hydrate Research and Development Act of 1997
Rayburn House Office Building, Room 2318
Washington, D.C.
September 15, 1998

Mr. Chairman and members of the subcommittee. My name is Arthur Johnson, and I am a senior staff geologist with Chevron USA Production Company in New Orleans. I am here today representing Chevron, the Natural Gas Supply Association (NGSA), and the National Ocean Industries Association (NOIA). NGSA represents integrated and independent companies that produce and market domestic natural gas. Established in 1965, NGSA encourages the expended use of natural gas and a regulatory climate that fosters competitive markets. NOIA is the sole trade group representing the entire spectrum of companies and individuals involved in the exploration and development of domestic offshore natural gas and petroleum resources. Included in this broad-based association membership of over 280 companies are Outer Continental Shelf operators, both majors and independents, offshore supply and service industries and drilling and diving contractors. I thank this committee for including some industry perspectives in its consideration of S 1418.

Methane hydrates are solid, ice-like substances composed of water and methane (natural gas). Methane hydrates occur naturally in areas of the world where methane and water occur together under the appropriate conditions of low temperature and high pressure. These conditions are found in deep water basins adjacent to continental shelves and in arctic regions. Naturally occurring hydrates have been observed off the Atlantic, Pacific and Gulf coasts of the United States and on the North Slope of Alaska. The U.S. energy industry first became aware of the existence of naturally occurring methane hydrates beneath the sea floor in the 1970s from the early work published in scientific journals by scientists at the U.S. Geological Survey and elsewhere. At the time, hydrates were viewed primarily as a curiosity. Given the water depths at which hydrates occurred, and the realities of natural gas price and supply, the common thought was that commercial development was perhaps twenty years into the future. Since that time the concept of methane hydrates as an energy resource has periodically reemerged, always with the speculation of enormous reserve potential, but always viewed as being viable twenty years in the future.

During the past five years, our perspectives on methane hydrates have changed dramatically. This is the result of research being conducted by the U.S. Geological Survey, the Naval Research Lab, the Department of Energy, the Ocean Drilling Program, and several universities. Some especially significant insights have come from ODP drilling at the end of 1995. During the past several years we have also seen a significant increase in hydrate-related activities in other countries, particularly Japan, India and Canada. The scope of these programs reflects the concerns these countries have regarding their energy future.

This research has given us two fundamental results. First, it has confirmed that huge amounts of methane hydrate exist on the continental margins and in the Arctic. Second, it has clarified many of the key technology issues that need to be resolved before commercial development can proceed.

At the same time that our knowledge of hydrates has increased, conventional oil and gas production in the Gulf of Mexico has moved into progressively deeper waters. We now have platforms, pipelines and other infrastructure in waters deep enough to have significant amounts of sub-sea methane hydrate. This has brought us to the current position where we can seriously consider the resource potential of methane hydrate. From an industry perspective, our greatest need is the development of reliable remote technology that would allow us to find and characterize locations where methane hydrates occur beneath the sea floor. While the published estimates of methane hydrate abundance are enormous, it is likely that most of the hydrate occurs in low concentrations and has no commercial potential. Our goal is to be able to find locations where the methane hydrates are sufficiently concentrated to warrant commercial production. In the near term, this technology will also provide valuable information on sub-sea hydrates related to conventional deep-water operations. This will help our industry maintain its excellent safety record in deep water. Besides finding and characterizing the hydrate resource, new technologies will also need to be developed for producing gas from sub-sea hydrates.

While the details of the proposed program have not yet been developed, the program directions discussed at the two DOE-sponsored workshops on hydrates appear to address industry needs quite well. There are excellent resources within the DOE labs, the U.S. Geological Survey, the Naval Research Labs, academia and industry. The proposed program is designed to integrate these resources to achieve the program goals.

We have concerns about the sufficiency of the proposed budget levels, and of the impact of insufficient funding on the timetable for the needed technology. These are areas that will need to be worked out, but I am confident that the proposed program can be developed in a way that achieves its goals in a cost-effective way. In conclusion, we believe that methane hydrates could hold significant potential as a domestic energy resource for the United States. We have much to learn before that potential can be adequately assessed and developed, and the program proposed through S 1418 appears to address these needs very well. We recognize a need to disseminate information about methane hydrates to the many individuals and organizations with an interest in hydrates, including policy makers and the general public. To that end, the Natural Gas Supply Association is developing a web site at hydrate.org.

Thank you, Mr. Chairman for the opportunity to share these views with you. I welcome any questions you and the subcommittee may have.

Statement of
Robert S. Kripowicz
Acting Assistant Secretary
for Fossil Energy
U.S. Department of Energy
Before the
Subcommittee on Energy and the Environment
Committee on Science
U.S. House of Representatives
September 15, 1998

Mr. Chairman and Members of the Subcommittee:

I am pleased to represent the Department of Energy and to present our views on the potential for methane hydrates as a future source of natural gas and more specifically, to review the progress we are making in preparing a multi-agency coordinated research plan for this potentially vast energy resource. I will also discuss our position on S. 1418, the Methane Hydrate Research and Development Act of 1997.

What Are Methane Hydrates?

Simply put, a methane hydrate is a cage-like lattice of ice, inside of which are trapped molecules of methane (the chief constituent of natural gas). In fact, the name for its parent class of compounds, "clathrates," comes from the Latin word meaning "to enclose with bars."

Methane hydrates form in generally two types of geologic settings: (1) on land in permafrost regions where cold temperatures persist in shallow sediments, and (2) beneath the ocean floor at water depths greater than about 500 meters where high pressures dominate. The hydrate deposits themselves may be several hundred meters thick.

Scientists have known about methane hydrates for a century or more. French scientists studied hydrates in 1890. In the 1930s, as natural gas pipelines were extended into colder climates, engineers discovered that hydrates, rather than ice, would form in the lines, often plugging the flow of gas. These crystals, although unmistakably a combination of both water and natural gas, would often form at temperatures well above the freezing point of ordinary ice. Yet, for the next three decades, methane hydrates were considered only a nuisance, or at best, a laboratory oddity.

That viewpoint changed in 1964. In a northern Siberian gas field named Messoyakha, a Russian drilling crew discovered natural gas in the "frozen state," or in other words, methane hydrates occurring naturally. Subsequent reports of potentially vast deposits of "solid" natural gas in the former Soviet Union intensified interest and sent geologists worldwide on a search for how -- and where else -- methane hydrates might occur in nature. In the 1970s, hydrates were found in ocean sediments.

In late 1981, the drilling vessel Glomar Challenger, assigned by the National Science Foundation to explore off the coast of Guatemala, unexpectedly bored into a methane hydrate deposit. Unlike previous drilling operations which had encountered evidence of hydrates, researchers onboard the Challenger were able to recover a sample intact.

Today, methane hydrates have been detected around most continental margins. Around the United States, large deposits have been identified and studied in Alaska, the west coast from California to Washington, the east coast, including the Blake Ridge offshore of the Carolinas, and in the Gulf of Mexico.

In 1995, the U.S. Geological Survey (USGS) completed its most detailed assessment of U.S. gas hydrate resources. The USGS study estimated the in-place gas resource within the gas hydrates of the United States to range from 112,000 trillion cubic feet to 676,000 trillion cubic feet, with a mean value of 320,000 trillion cubic feet of gas. Subsequent refinements of the data in 1997 using information from the Ocean Drilling Program have suggested that the mean should be adjusted slightly downward, to around 200,000 trillion cubic feet -- still larger by several orders of magnitude than previously thought and dwarfing the estimated 1,400 trillion cubic feet of conventional recovered gas resources and reserves in the United States.

Worldwide, estimates of the natural gas potential of methane hydrates approach 400 million trillion cubic feet -- a staggering figure compared to the 5,000 trillion cubic feet that make up the world's currently known gas reserves.

This huge potential, alone, warrants a new look at advanced technologies that might one day reliably and cost-effectively detect and produce natural gas from methane hydrates.

Why the New Interest in Hydrates?

If only 1 percent of the methane hydrate resource could be made technically and economically recoverable, the United States could more than double its domestic natural gas resource base.

The United States will consume increasing volumes of natural gas well into the 21st century. U.S. gas consumption is expected to increase from almost 23 trillion cubic feet in 1996 to more than 32 trillion cubic feet in 2020 -- a projected increase of 40 percent.

Natural gas is expected to take on a greater role in power generation, largely because of increasing pressure for clean fuels and the relatively low capital costs of building new natural gas-fired power equipment. Also, gas demand is expected to grow because of its expanded use as a transportation fuel and potentially, in the longer-term, as a source of alternative liquid fuels (gas-to-liquids conversion) and hydrogen for fuel cells. Should the nation move to reduce carbon dioxide emissions, as part of our commitment to greenhouse gas reduction, the use natural gas potentially could increase even more.

Given the growing demand for natural gas, the development of new, cost-effective supplies can play a major role in moderating price increases and assuring consumer confidence in the long-term availability of reliable, affordable fuel. Yet, today, the potential to extract commercially-relevant quantities of natural gas from hydrates is speculative at best. With no immediate economic payoff, the private sector is not vigorously pursuing research that could make methane hydrates technically and economically viable. Therefore, federal R&D is the primary way the United States can begin exploring the future viability of a high-risk resource whose long-range possibilities might one day dramatically change the world's energy portfolio.

A Vast New Source of Energy or a Safety and Environmental Hazard?

Methane hydrates represent a tantalizing energy prospect; yet, at the same time, there are significant safety and environmental issues. The hydrate structure encases methane at very high concentrations. A single unit of hydrate, when heated and depressurized, can release 160 times its volume in gas.

Computer simulations indicate that thermal recovery methods, such as the use of hot water or steam flooding, could make hydrates a technically recoverable resource. Alternatively, methods that dissociate the gas by reducing the reservoir pressure may be possible. Chemical injection to decrease the stability of the hydrate lattice could be another approach.

This potential for large volumes of methane to be released due to destabilization of the hydrate formation can also create safety problems, however. Offshore operators are increasingly reporting problems of drilling through hydrates. Normal-speed drilling generates sufficient heat to decompose surrounding hydrates, resulting in high-gas-content mud that can contribute to loss of well control. Hydrates also can form either in the well bore or in connecting lines, plugging the flow. Also, as hydrates decompose, particularly at or near the sea floor, subsidence can occur, potentially causing a loss of foundation support for offshore platforms or possibly damaging underwater cables.

Research into methane hydrates, therefore, could benefit conventional oil and gas operations by developing improved methods to anticipate and diagnose the presence of these formations. As producers move increasingly into regions where hydrates are likely to be found, the federal R&D program could provide important information to mitigate safety and environmental hazards.

DOE's Previous R&D Program

The Glomar Challenger's retrieval of a 3-foot long hydrate core in 1981 -- the only one at that time known to exist in the Western Hemisphere -- intensified interest in methane hydrates. The core was shipped to the Colorado School of Mines, which asked several organizations for proposals on how they would study the sample. Six organizations were chosen to carry out the analyses, including the Department of Energy's Morgantown Energy Technology Center, now part of the Federal Energy Technology Center. (The others were the USGS at Menlo Park, CA; the National Bureau of Standards in Boulder, CO; the University of California at Los Angeles; Texas A&M University; and the Sohio Research Center in Cleveland, OH.)

The core studies kicked off a new effort by the DOE Office of Fossil Energy to study the physical and chemical properties of hydrates, the mechanisms for their formation and dissociation, and the geological characteristics of marine and Arctic hydrate formations.

From 1982-1992, DOE's methane hydrate program spent $8 million in developing a foundation of basic knowledge about the location and thermodynamic properties of gas hydrates. The DOE-supported program: established the existence of hydrates in the Kuparuk Field on the north slope of Alaska; completed studies of 15 offshore hydrate basins; developed production models for depressurizing and heating hydrates release gas, developed preliminary estimates of gas-in-place for hydrate deposits, and built the Gas Hydrate and Sediment Test Lab Instrument, a device that can form hydrates within sediments in a laboratory chamber that simulates deep sea conditions.

DOE's initial methane hydrate research ended as priorities shifted to more near-term exploration and production R&D. Work continued at relatively small scales at the USGS, universities, other laboratories, and overseas. Studies of the Blake Ridge formation offshore of the Carolinas in 1995 (part of the USGS Ocean Drilling Program Leg 164) contributed significantly to our understanding of hydrates and a refinement of potential resource estimates.

In FY 1997 and FY 1998, DOE provided a small amount of funding from its Natural Gas Supply Program to support activities in preparation for a more definitive program proposed for FY 1999. We participated in the testing and sample analysis of a 1,200-meter deep well in the Mackenzie Delta of Canada drilled by Japan National Oil Company. We also began processing and evaluating seismic data from the hydrate regions of the Gulf of Mexico, and began designing a global database of gas hydrates and related gas deposits. The Department also began participating in the Colorado School of Mines gas hydrate university/industry consortium which is studying the problem of hydrate plugging in conventional wells and handling facilities.

The Development of a New Gas Hydrate R&D Initiative

In its 1997 report, the Energy Research and Development Panel of the President's Council of Advisors on Science and Technology (PCAST) recommended "a major initiative for DOE to work with USGS, the Naval Research Lab, Mineral Management Service, and the industry to evaluate the production potential of methane hydrates in U.S. coastal waters and world wide." PCAST also called attention to the possibility that studies of methane hydrates could lead to possible sequestering of carbon dioxide in CO_2 hydrates.

On January 21-22, 1998, DOE hosted a workshop in Denver on the "Future of Methane Hydrate Research and Resource Development." The objective was to take the first step in developing, jointly with the Department of the Interior and the Department of Defense (Naval Research Laboratory), a new R&D program for methane hydrates.

On May 12, 1998, a second workshop was held in Washington, DC, specifically to review a "strawman" Methane Hydrates Program Plan that outlined a four-pronged approach to answering the key questions concerning future methane hydrate production:

1) How Much?
Research Needs The huge range in estimates of hydrate volume underscores the lack of detailed understanding of the location, volume, physical character, and formation mechanisms of hydrate deposits in the United States and the world.

Program Goal: Determine the location and sedimentary relationships of methane hydrate resources to assess their potential as a domestic and global fuel resource.

2) How to Produce the Resource?
Research Needs: In only one documented instance (and this is debated), there appears to be commercial gas production with replenishment from hydrates. Much more work in depressurization, thermal processes, and solvent injection is needed to document and field test these techniques.

Program Goal: Develop the knowledge and technology necessary for commercial production of methane from oceanic and permafrost hydrate systems by 2015.

3) How to Assess Impact?
Research Needs: Virtually nothing is known about the stability of gas hydrates, especially those dispersed along the sea floor, in a period of global climate change. For example, could global warming affect outcrops of methane hydrates at the sea floor and lead to significant releases of methane, a gas that is 20 times more potent than carbon dioxide as a greenhouse gas? The fate of methane in seawater is just as unclear.

Program Goal: Develop an understanding of the dynamics and distribution of oceanic and permafrost methane hydrate systems sufficient to quantify their role in the global carbon cycle and climate change.

4) How to Ensure Safety?
Research Needs: Arctic and marine hydrates are known to cause drilling problems, blowouts, casing collapse, and well-site subsidence in conventional drilling and production. Research is needed to accurately document drilling and production problems caused by gas hydrates and to develop techniques to avoid or mitigate hazards. Long-term impacts on sea floor stability and

safety due to methane production from hydrates must also be investigated. It is not known, for example, if hydrate production might lead to sea floor subsidence.

Goal: Develop an understanding of the hydrate system in near-sea floor sediments and sedimentary processes, including sediment mass movement and methane release so that safe, standardized procedures for hydrocarbon production and ocean engineering can be assured.

The Department has also posted the draft Methane Hydrates Program Plan on its Fossil Energy Web Site (http://www.fe.doe.gov) and has provided a way for external users to submit comments on the plan electronically.

The results of the two workshops and the stakeholder comments will be incorporated into a final Program Plan scheduled for completion in June 1998. This plan will form the basis for further R&D in FY 1999 and beyond.

Because future program activities are still in the formative stage, DOE requested only a minimal level of R&D funding in its fiscal year 1999 budget submission to Congress. Included in the budget proposal is $500,000 to begin answering the key uncertainties that must be addressed before methane hydrates become a commercially realistic energy resource.

The Department's Views on S. 1418, the Methane Hydrate Research and Development Act

S. 1418 would promote the research, identification, assessment, exploration, and development of methane hydrate resources. This legislation provides a clear endorsement from Congress of federal research efforts to better understand the true energy potential of methane hydrates. S. 1418 is consistent with the goals we have established for the federal hydrates R&D program; therefore, the Department can support this legislation.

We are particularly pleased to see the Congress emphasize in Sec.3 (d)(1), the need to facilitate and develop partnerships among government, industry and academia in future hydrate R&D. This concept of a public-private partnership, with shared responsibilities and resources, is fundamental to our fossil energy R&D program. It is particularly important that the private sector, which will ultimately be responsible for converting R&D results into commercially-viable production methods, be part of the project team early in the R&D process. We expect to see substantial industry cost-sharing in those activities that have significance for current drilling practices, such as the studies of hydrate mechanical properties and ocean engineering that I mentioned in Goal 4 above. As other longer-term technologies mature, we expect the proportion of industry cost-sharing in these areas to increase to significant levels. We also will seek a wide range of private sector and academic partners. This will expedite significantly the transfer of technology that evolves from this effort.

We also applaud the Congressional direction to "ensure that data and information developed through the program are accessible and widely disseminated....". Working with the Natural Gas Supply Association and the International Centre for Gas Technology Information, we are proposing to develop a methane hydrates Internet site that will be used to enhance information dissemination among the world's community of hydrate researchers and technology users, as well as to obtain stakeholder input.

We are also pleased that the Congress has recognized the importance of cooperation among Federal agencies in developing potentially promising hydrate technologies. We would not be nearly as well positioned to begin a new, intensified examination of the hydrate potential had it not been for the excellent work of the USGS and the Naval Research Laboratory. The coordinated involvement of these organizations, along with others such as the National Science Foundation, the Minerals Management Service, the Interstate Oil and Gas Compact Commission, and the Gas Research Institute, will be essential in carrying out a productive and effectively managed R&D program.

This concludes my prepared statement. I will be pleased to answer any questions you or Members of the Subcommittee may have.

APPENDIX 2

TEXAS A&M UNIVERSITY

Geochemical & Environmental Research Group
College of Geosciences & Maritime Studies
Dr. Roger Sassen

4 March 1999

TO: Jennifer Peterson/MMS
FROM: Roger Sassen

SUBJECT: GAS HYDRATE RESEARCH DIRECTIONS

Dear Jennifer:

Thank you for calling, and asking about gas hydrate research directions. Permit me to express my opinions, with the understanding that others might not see it exactly the same way. My opinions have been influenced by an intimate understanding of energy company activities on the Gulf slope over the last 20 years.

There has been much emphasis on gas hydrates as a future resource, which matters to the M.M.S. Although the energy resource is there, time is not a pressing issue. For the next few decades, conventional energy supplies are likely to be both abundant and low price. Nevertheless, we have been addressing the resource issue by regional mapping of gas hydrates across the Gulf, by analyzing gas hydrates to classify them by origin, and by modeling maximum depths of gas hydrate preservation. Improved estimates of gas hydrate resource will result from putting this information in a regional geologic context. Publications are being prepared, and we are putting together a preproposal for ODP drilling in this regard.

Much of our research has been involved in the relationship of gas hydrate to life in extreme environments, which I find to be extremely exciting. This direction of research resulted from M.M.S. support of research on Gulf of Mexico chemosynthetic communities managed by Bob Avent. But once again, this type of research can move forward in a deliberate manner. We are working with JPL/NASA on the implications of gas hydrate to possible life in Lake Vostock beneath 3.5 km of Antarctic ice, with implications to future exploration of Europa, projects with long development times.

However, what most concerns me real-time is that the energy industry is moving into deep water of the Gulf of Mexico where gas hydrates form instantaneously in sea-floor experiments. The rapid rate at which gas hydrates form (and probably decompose) in natural settings was not addressed until simple sea floor experiments were done using research submarine platforms. Soft sediment deformation from gas hydrate could affect pipelines and sea-floor infrastructure. Gas hydrates could form in drilling mud, impacting physical properties and raising safety issues. Surprisingly little is known about the geology (water depth distribution, geologic controls, maximum preservation depth in sediments) and geochemistry (compositions and stability realms) of natural gas hydrates in the context of energy industry activities. Our belief is that present models of gas hydrate formation need to be "tuned" by further insight to complex natural settings. We see an immediate need for applied research on gas hydrates as a potential hazard to drilling and production in the Gulf slope. We simply cannot afford a major accident in the deep waters of the Gulf, and thus have a clear common objective with the MMS. Dr. Mike Smith is aware of this concern.

In giving presentations on natural gas hydrates to the energy industry, I found that knowledge of potential gas hydrate hazards is limited. There is the tendency within the energy industry to decrease time between discovery and production, and to use new and innovative technology, in an effort to decrease costs. At the same time, internal energy company research has been scaled back. These circumstances could potentially increase risk in a relatively unknown environment. Gas hydrate related problems have occurred in deepwater environments elsewhere, but they have not always been widely publicized.

One of the goals of the Applied Gas Hydrate Research Program (AGHRP), therefore, is technology transfer and basic training to various energy companies. Perhaps the MMS needs to know more about potential gas hydrate hazards to fulfill its mission in the Gulf of Mexico, and one way to do that is to fund applied research on natural gas hydrates in that area internally and through universities.

Once again, let me stress that the above is informed opinion. But it appears to me that the role and the needs of the M.M.S. in applied gas hydrate research could be larger than first anticipated.

Best wishes to you and your associates.

Cordially,

Roger Sassen

Deputy Director, Resource Geosciences

CT: Chuck Kennicut/Jeanie Baggett

APPENDIX 3

Literature Survey: Recent Gas Hydrate Publications

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The Department of the Interior Mission

As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally owned public lands and natural resources. This includes fostering sound use of our land and water resources; protecting our fish, wildlife, and biological diversity; preserving the environmental and cultural values of our national parks and historical places; and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to ensure that their development is in the best interests of all our people by encouraging stewardship and citizen participation in their care. The Department also has a major responsibility for American Indian reservation communities and for people who live in island territories under U.S. administration.

The Minerals Management Service Mission

As a bureau of the Department of the Interior, the Minerals Management Service's (MMS) primary responsibilities are to manage the mineral resources located on the Nation's Outer Continental Shelf (OCS), collect revenue from the Federal OCS and onshore Federal and Indian lands, and distribute those revenues.

Moreover, in working to meet its responsibilities, the **Offshore Minerals Management Program** administers the OCS competitive leasing program and oversees the safe and environmentally sound exploration and production of our Nation's offshore natural gas, oil and other mineral resources. The MMS **Royalty Management Program** meets its responsibilities by ensuring the efficient, timely and accurate collection and disbursement of revenue from mineral leasing and production due to Indian tribes and allottees, States and the U.S. Treasury.

The MMS strives to fulfill its responsibilities through the general guiding principles of: (1) being responsive to the public's concerns and interests by maintaining a dialogue with all potentially affected parties and (2) carrying out its programs with an emphasis on working to enhance the quality of life for all Americans by lending MMS assistance and expertise to economic development and environmental protection.