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Japan-Russia Development Status of Technologies for Methane Hydrate Resource Development

Methane Hydrate Research and Development Program of Japan - Outline and Achievements -

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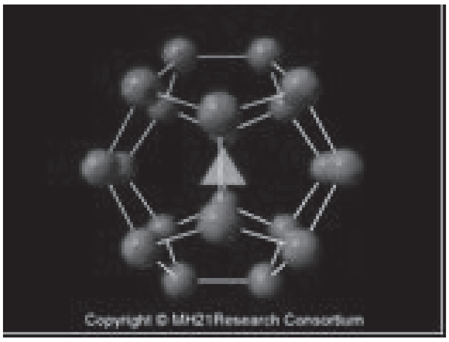
What is methane hydrate?

Methane hydrate is a substance with methane molecules confined in a basket structure formed by water molecules. Because it is apparently an ice-like substance, it is sometimes called "burning ice."One volume of hydrate contains 160 to 170 volumes (at 0°C and 1 atmospheric pressure) of methane.

Figure 1 Molecular structure of methane hydrate



Methane hydrate exists in an environment of "low temperature and high pressure." For example, it can stably exist at a temperature of -80°C or lower under a pressure of 1 atmosphere (normal atmospheric pressure), at -30°C or lower under a pressure of 10 atmospheres, at 6°C or lower under a pressure of 50 atmospheres, and at +12°C or lower under a pressure of 100 atmospheres. In the natural world, methane hydrate can stably exist in environments meeting the above temperature and pressure conditions such as within geological layers located 1,000 meters deep underground in polar regions with thick permafrost in the terrestrial area; or within geological layers located at several hundred meters under the seafloor or on the seafloor surface at a water depth of 500 meters or deeper in the sea area. Methane hydrate has been discovered on the deep sea floor surface or under the permafrost in various parts of the world as a result of scientific researches.

Figure 2 Global locations of methane hydrate discovery

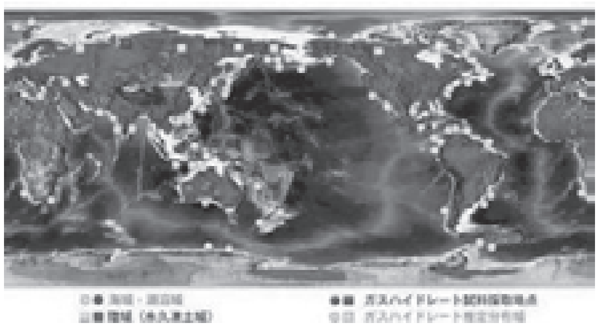
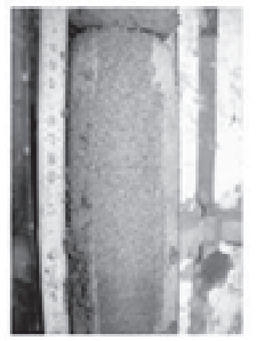


Fig. 3 Hydrate discovered in a sand layer by basic test boring



Background and Research and Development Programs for Methane Hydrate Study in Japan

In 1999 basic test boring of the "Nankai Trough," which was excavated in the southern sea area of Japan under commission from the Ministry of Economy, Trade and Industry (METI), revealed for the first time in the world that methane hydrate exists on a mass scale in the manner of filling the vacant spaces (pores) between sand grains formed in geological layers formed by sand under the deep sea floor surface (in a similar manner as normal oil). In light of this result, METI formulated the "Methane Hydrate Development Research Program (Phase 1 to 3)" in 2001 from the medium-to-long term viewpoint of exploring the possibility of methane hydrate as a future energy source.

Research and Development Organization for Promotion

In response to the formulation of the program, it was decided that the Japan National Oil Corporation (the present Japan Oil, Gas and Metals National Corporation

(JOGMEC)); the National Institute of Advanced Industrial Science and Technology (AIST), which is a national research institution engaged in a wide range of technological development; and the Engineering Advancement Association of Japan (ENAA), which is comprised chiefly of private-sector engineering companies, will form the MH21 Research Consortium JAPAN (abbreviated as MH21) to perform the phase 1 research and development in cooperation while playing the role of "resources estimation," "production engineering/modeling," and "environmental impact assessment," respectively.

Objectives and Goals for Research and Development

This research program aims to contribute to the long-term stable supply of energy by exploring methane hydrate and promoting the development of technologies enabling the economic production of methane. This program targets methane hydrate present in sand layers (vacant spaces) under the sea floor.

Goals

1. To grasp the presence of methane hydrate in sea areas surrounding Japan
2. To estimate the quantity of methane gas in hydrate layers of highly potential regions.
3. To assess cost efficiency of resource mining for highly potential areas.
4. To perform a productivity test in such areas.
5. To improve the technology toward economic gas production.
6. To construct an environmentally-friendly development system.

Major Achievements in the Phase 1 Study

1. The existence of methane hydrate on a mass scale in sand layers under the seafloor surface in the manner of filling vacant sandy spaces was revealed for the first time in the world by a winze.
2. A technique for evaluating methane hydrate accumulated zones with several seismic parameters was developed (exploration technique).
3. The quantity of methane contained in the hydrate of the Eastern Nankai Trough was estimated with high accuracy.
4. A winze was excavated in a permafrost zone and methane was produced continuously by decomposing hydrate underground using pressure reduction.
5. A method of testing a core sample collected from an underground hydrate layer under the same temperature and pressure conditions was established.
6. A method of measuring the physical property of hydrate under the underground conditions was established. In addition, a standard technique for preparing and testing an artificial sample simulating hydrate in sand was developed.
7. A special numeric simulator capable of analyzing the decomposition/flow etc. of hydrate was developed for use in the evaluation of core test results and production tests.

Figure 4 Establishment of a technique for exploring methane hydrate in a sand layer

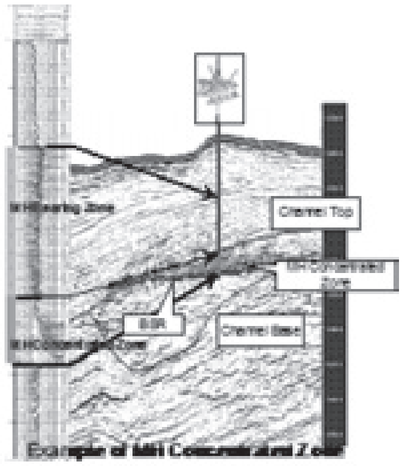
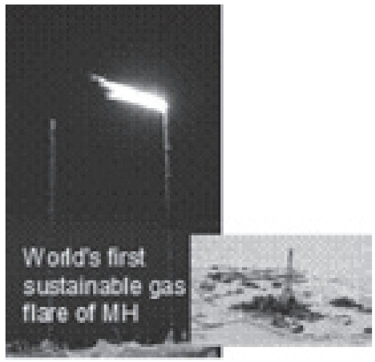


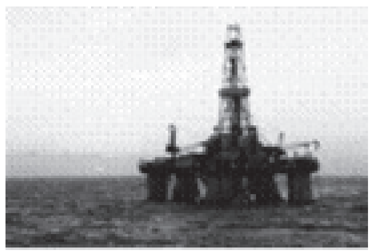
Figure 5 Success in continuous production for the first time in the world



Major Technical Issues in Phase 2

1. Evaluation of the presence of methane hydrate in sea areas outside of the Eastern Nankai Trough
2. Long-term production test
3. Oceanic production test
4. Consideration of more efficient production method
5. Environmental impact assessment

Figure 6 Phase 2 targets an oceanic production test in the sea close to Japan



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Japan-Russia Cooperation in the Field of Gas Hydrate Development: Proven Experience and Future Issues

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A gas hydrate is apparently an ice-like crystalline material. It is formed in a sufficiently high concentration (fugacity, pressure) by water and low-molecular gas at a relatively low temperature. Gas hydrates compete head to head against the traditionally used reserves for their advantages of being immature resources derived from a particular natural gas, being widespread, and being excellent underground resources that will be gasified in the form of a thick gas. A major goal of the investigation in the gas hydrate geological issue is to clarify the role of natural gas hydrate (chiefly existing on the sea floor) as a potential fuel. In addition, it is necessary to understand the locations and ranges where gas hydrates are distributed and to accurately estimate the quantities of the concentrated gas reserved in the dispersed gas hydrate sedimentary layers. An offshore gas hydrate may contain gas reserves of 2×10^{14} - 7600×10^{15} cubic meters. Given that offshore gas hydrate may be replaced as a principal energy resource in the world, resolving the importance of the natural gas hydrate resource is one of the most realistic agendas of oil and gas geology.

The Russian Laboratory for Unconventional Hydrocarbon Resources from I.S. Gramberg Academician All-Russian Research Institute for Geology and Mineral Resources of the World's Oceans (I.S. Gramberg VNIIOkeangeologia) was established in 1982. At present, this institute is recognized by Russian and international science communities as an institute capable of sufficiently investigating the gas hydrate geology from various perspectives (geochemistry, geothermal heat, sedimentology, physical chemistry, resources, etc.) We were engaged in the discovery and studies of gas hydrate sedimentary layers in the Norway, Black Sea, Caspian Sea, Sea of Okhotsk, North Atlantic Ocean (submarine ridge in the Black Sea depths., Cadiz Bay), Lake Baikal, and Messoyakha gas fields. VNIIOkeangeologia has succeeded in cooperating in the field of natural gas hydrate study with institutes in Japan (KIT), Korea (KORDI, KOPRI), Belgium (RCMG), Germany (GEOMAR), Bulgaria (Oceanologic Institute), United States (NRL), Canada (University of Victoria), Azerbaijan (Geological Institute), and so forth.

One of such successful examples of international cooperation is the CHAOS (Hydro-Carbon Hydrate Accumulations in the Okhotsk Sea) project. This project aims to study the gas hydrate formation process in a fluid discharge structure (gas leakage) in the Sea of Okhotsk. The idea of this project was issued by the Kitami Institute of Technology (KIT, Prof. Hitoshi Shoji) of Japan and VNIIOkeangeologia (V. Soloviev) of Sankt Petersburg that are new energy resource research centers. Professor Anatoly Obzhirov, who is the head of the Marine Geology/Geophysics Department of the Pacific Oceanological Institute FEB RAS (Vladivostok), is in charge of the promotion of the technological support. Particular data sets obtained after five explorations enabled the evaluation of gas resources in those hydrate sedimentary layers. The work was performed under the support of the Japan Society for the Promotion of Science; the Ministry of Education, Culture, Sports, Science and Technology; the Kitami Institute of Technology; the Russian Federation Program "World's Oceans"; and the Russian Foundation for Basic Research. The brilliant achievements of the joint project further improved the future outlook of the development of the wide-ranging Japan-Russia cooperation network in specialized fields of gas hydrate study.

Thus, with the proven experience of the VNIIOkeangeologia-KIT joint study, we can expect to win the interest of other scientific groups and organizations in Japan in the studies and related industries of gas hydrate.

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Gas Hydrate and Methane Flux in the Sea of Okhotsk and How to Mine Methane from Them

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This research aims to discover a sedimentary-layer-related, geological or geophysical law of gas hydrate fields in the Sea of Okhotsk. Investigation will be performed on the prospect of methane flux in the water column directly connecting the sedimentary layer to a gas hydrate and the prospect of methane in the gas hydrate, and the environmental impacts on the methane flux.

- Gas hydrate exploration method in an ocean
- Study on a geological law generating or destroying a gas hydrate
- Establishment of a scientific basis for the prospect of methane in several related gas hydrates—methane flux not causing environmental destruction existing in the Sea of Okhotsk

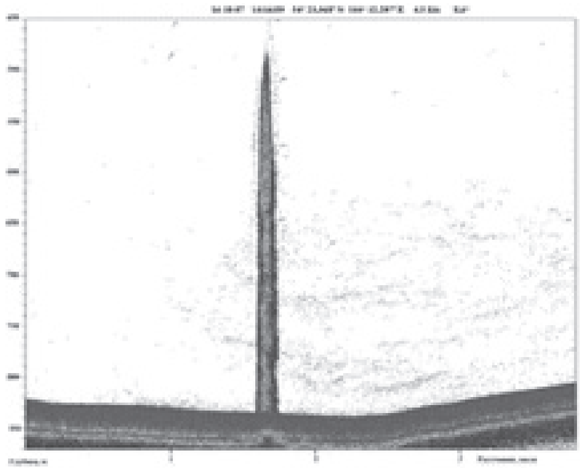
Geological or geophysical complex investigations were performed to study methane flux and gas hydrate in the Sea of Okhotsk through the international projects of Russia and Germany (KOMEX, 1998-2004); and Russia, Japan, and Korea (CHAOS, 2003, 2005-2006), and are still under way through the international project of Russia, Japan, and Korea (SAKHALIN, 2007-2012).

Geological or Geophysical Characteristics of Gas Hydrate Fields

Regularities seen in common among gas hydrates distributed in the world's oceans and in the Sea of Okhotsk have been examined so far. It was concluded that a hydrate is related to an oil and gas deposit layer and that methane flux is related to seismoacoustic/crustal movement activities. The hydrocarbon content of the gas hydrate was investigated to examine the methane flux in the atmosphere and the impacts of the methane flux on global-scale climate changes and aquatic biota. The above investigation is continuously under way in the SAKHALIN project to obtain more detailed geological, geophysical, underwater sound, and gas geochemical parameters in the gas hydrate fields.

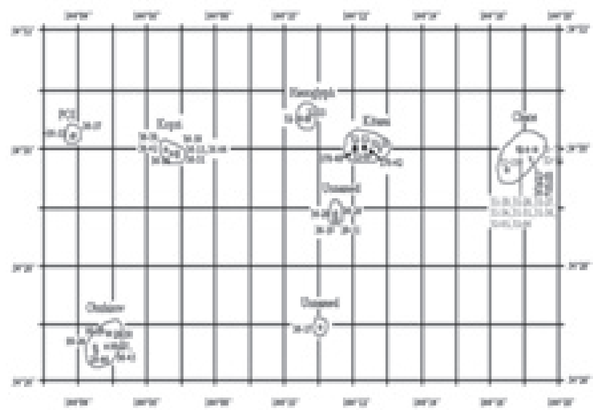
During the period from 1998 to 2009, numerous (approximately 500) methane fluxes were discovered on the slopes of the Sakhalin northeast continental shelf in the Sea of Okhotsk (Fig. 1).

Figure 1 Underwater sound image of the methane gas bubble fluxes emitted from the sedimentary layer into the water in the Sea of Okhotsk



In this region, 11 gas hydrate fields were discovered (Fig. 2). The methane sources of the gas hydrate are mostly thermal gas in the oil and gas deposit layer located on the slopes of the Sakhalin continental shelf and of the Okhotsk Sea continental shelf.

Figure 2 Methane fluxes and gas hydrates existing in the Sakhalin continental shelf of the Sea of Okhotsk (the enclosed regions indicate gas hydrate fields and the dots inside the enclosures indicate methane fluxes)

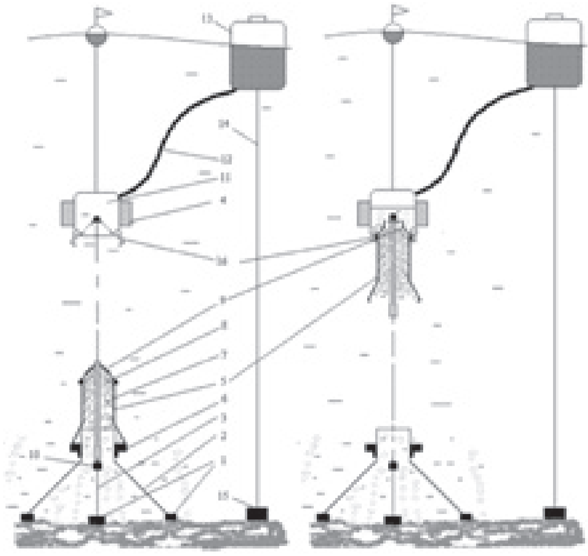


Plan of Mining Methane from Gas Hydrates

Methane extraction will be implemented from gas hydrates or methane fluxes by reducing pressure to the atmospheric pressure in consideration of commercial profitability. The following model (Fig. 3) is proposed as one method of extracting methane from gas hydrates or methane fluxes.

Because methane bubbles contain numerous traps, the gas will be lifted using a special gas extractor. This extractor will rise with the progress of gas mining. The vessel will receive the gas filled in the extractor at a certain number of traps (by every 50 traps for example) and return to the starting position after receiving the final trap. This cycle will be repeated.

Figure 3 Methane bubble gas extractor used in the gas hydrate fields



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Results and Perspectives of Search and Research of the Baikal Gas Hydrates

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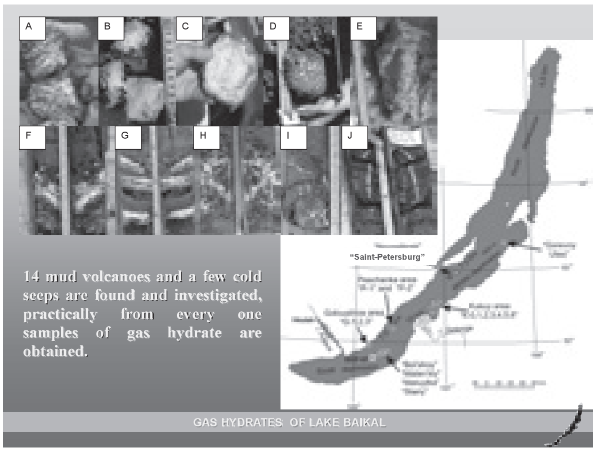
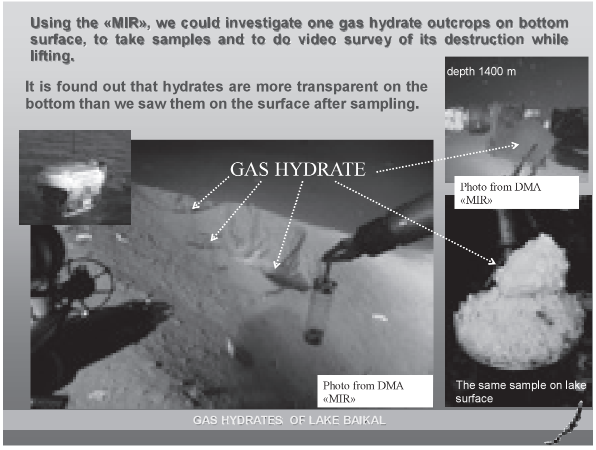
The information about regions with prospective gas hydrate deposits within the freshwater area of Lake Baikal was released for the first time in 1980 by VNIIGAZ. Based on the information, explorations by multi-channel seismic wave measurement were performed in 1989 and 1992. After the explorations, BSR (bottom simulating reflector), which is a geophysical sign indicating a region where hydrate-containing water exists could be obtained from a sedimentary layer in Lake Baikal. A BSR map was created from the exploration result of the delta area along the Selenga River in 1992, which enabled for the first time the prospective analysis of gas hydrate reserves within an area of 8.8×10^{11} - 9×10^{12} cubic meters.

In 1997, the first sample of deep sea gas hydrate (a species of methane of biological origin in cubic structure of KC-1) was collected at points 121 m and 161 m from the lake bottom at a depth of 1,420 m. During the geological and geophysical activities performed from 1999 to 2009, fourteen mud volcanoes were discovered in four mud volcano areas at the bottom Lake Baikal. Gas hydrates and one oil spill site were identified in seven mud volcanoes of the above.



A deposit of gas hydrate was identified near the surface of the lake bottom also in the gas hydrate survey that we promoted. The samples obtained from the deposit were revealed to simultaneously compose both KC-1 hydrate, which is methane of biological origin, and KC-2 hydrate, which is a mixture of thermal ethane and biological-origin methane. In 2009, a hydrate, which emerged on the lake bottom surface, was filmed using an underwater video camera DMA"MIR."

The numerous experiences obtained from the gas hydrate surveys of Lake Baikal enable us today not only to continue a large-scale basic investigation, but also to develop and test a mining gas technology from near the surface of the gas hydrate sedimentary layer. This project will be implemented as SB RAS (Siberian Branch of the Russian Academy of Sciences) Integrated Project No.27.



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Experiment of Gas Recovery from Methane Hydrate in the Lake Bottom Surface Layer of Lake Baikal

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I report an experiment of gas recovery from a methane hydrate in the lake bottom surface layer performed in Lake Baikal in August of last year. This experiment was implemented jointly by Shimizu Corporation; Kitami Institute of Technology; Hokkaido University; and the Limnological Institute SB RAS, Irkutsk, Russia, under commission from the Innovative Technology Development Research Project adopted in fiscal 2006 of the Japan Science and Technology Agency.

The methane hydrate clustering patterns are largely divided into two. One is a methane hydrate existing in the "deep layer" of the sea bottom or lake bottom that clustered in the permeable layer within the ground slowly over an extended period of time. The other is a methane hydrate that was clustered in the "surface layer" on the sea bottom or lake bottom by a sudden gas flow from the bottom caused by faulting within the ground or by mud volcano activities. The deep-layer type methane hydrate can be decomposed with the equilibrium state collapsed only by a slight change in temperature or pressure conditions. Whereas, the surface-layer type methane hydrate with low water temperature needs much energy to change to the equilibrium state. A method of recovering gas by gasifying hydrates through decomposition is proposed for the deep-layer type methane hydrate resource development. The surface-layer type methane hydrate, however, needs a different method for gas recovery.

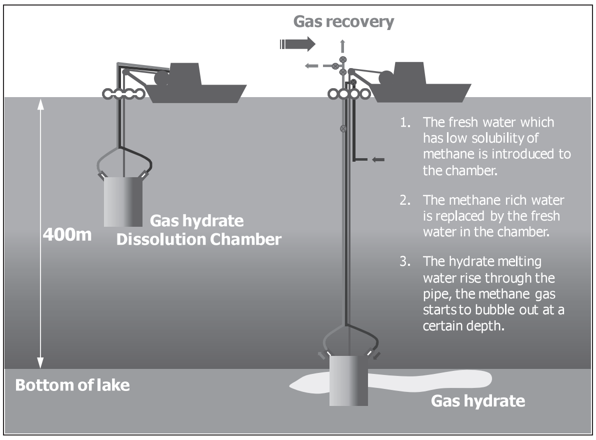
For the deep-layer type methane hydrate, research study has been implemented for the past 10 years and concrete production techniques have also been under investigation. For the surface-layer type methane hydrate, the investigation has not been advanced yet although it has been identified in the sea close to Japan. Under such circumstances, however, it was decided to implement a gas recovery experiment as a pilot study in Lake Baikal by applying a new production technique of recovering gas by resolving a methane hydrate in water, in light of the potential usefulness of the surface-layer type methane hydrate for securing of the precious domestic energy supply source.

Lake Baikal is the only freshwater lake in which the existence of methane hydrates has been identified. There also exist methane hydrates derived from mud volcanoes on the surface layer of the lake bottom. A cone penetration test was performed to grasp the existence, depositional depth, and occurrence of methane hydrate layers as well as sampling inspection for such mud volcanoes to evaluate the physical properties of methane hydrate, interstitial water, and sedimentary soil.

In order to verify the proposed gas recovery method, a gas recovery experiment was performed at a site in the south lake basin of Lake Baikal. Methane hydrates on the lake bottom were excavated/stirred by the water jet attached to the end of the dissolution chamber settled on the lake bottom while feeding water with a lower methane dissolution concentration from the lake surface layer to the methane hydrates and gasifying by pumping up water dissolved from and mixed with the methane hydrates, and the gas was recovered into the vessel. The gas recovery experiment revealed that gas with a hydrocarbon concentration of 90% or higher was recovered. The analytical result of gas composition and isotope ratio revealed that the recovered gas was chiefly composed of dissolved gas from the methane hydrates.

The current experiment aimed to verify the gas recovery technique for methane hydrates in the lake bottom surface layer. The improvement of the gas recovery efficiency and the assessment of cost efficiency remain as future issues. Given, however, that this experiment was the first successful case of gas recovery from a hydrographic area, I believe that this experiment could indicate the possibility of the resource development of surface-layer type methane hydrates as one method option.

Summary of the Gas Recovery Experiment



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Importance of the Site Investigation for Development of Methane Hydrate

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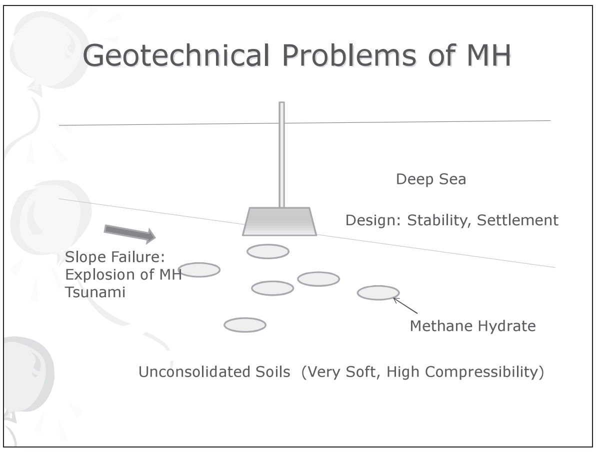
Few cases exist in conventional resource development, where the ground strength became problematic, except in the development of oil or natural gas deep underground. That is because the resources conventionally collected by mankind such as coal and oil exist in solid bedrock (or consolidated soil using the technical term). Given the existence of methane hydrates within the unconsolidated soil, the ground characteristics will become significantly problematic.

Aspects that will become problematic in terms of geotechnical engineering in the development of methane hydrates are construction of the foundation for mining as shown in the figure and the ground stability after resource mining. In particular, the latter may cause a large-scale submarine landslide with the development on an unstable seabed as the trigger. In order to solve such issues, the physical property of the ground required for the prediction needs to be measured with high accuracy.



The unconsolidated soil became problematic in the past chiefly in the field of construction. Human activities are performed chiefly in places consisting of thick deposition of unconsolidated soil as represented by alluvial plains especially in Japan. Construction of buildings or roads on such a place may cause significant ground subsidence or ground collapse in some cases. Accordingly, in order to prevent those issues, subsurface investigation methods were developed in the field of civil engineering and construction. The technologies cultivated in such a way cannot be applied to the methane hydrate developed as they are. What may impose a major impediment in the application is the water depth. Economically developable sea areas for purposes other than resource development are a depth shallower than 50 m at best. For example, the water depth of Kansai International Airport constructed on a man-made island is 20 m. A technology enabling seabed investigation at a water depth in excess of 1,000 m needs to be developed immediately.