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The U.S. Geological Survey's Gas Hydrates Project

The Gas Hydrates Project at the U.S. Geological Survey (USGS) focuses on the study of methane hydrates in natural environments. The project is a collaboration between the USGS Energy Resources and the USGS Coastal and Marine Geology Programs and works closely with other U.S. Federal agencies, some State governments, outside research organizations, and international partners. The USGS studies the formation and distribution of gas hydrates in nature, the potential of hydrates as an energy resource, and the interaction between methane hydrates and the environment. The USGS Gas Hydrates Project carries out field programs and participates in drilling expeditions to study marine and terrestrial gas hydrates. USGS scientists also acquire new geophysical data and sample sediments, the water column, and the atmosphere in areas where gas hydrates occur. In addition, project personnel analyze datasets provided by partners and manage unique laboratories that supply state-of-the-art analytical capabilities to advance national and international priorities related to gas hydrates.

Figure 1. In 2010, the U.S. Geological Survey recovered white chunks of gas hydrate (methane ice) mixed with gray sediment a few feet below the sea floor in the Arctic Ocean at a water depth of approximately 8,000 feet.

Gas hydrate forms when water and gas combine under specific relatively high pressure and low temperature conditions to make an ice-like solid (fig. 1). Methane, a chemical compound made up of one carbon and four hydrogen atoms, is the main component of natural gas and the most common gas in natural hydrate. The methane that becomes trapped in gas hydrate usually originates when micro-organisms break down carbon-rich organic material that is deposited in sediments. Methane migrating upward from conventional natural gas reservoirs can also be trapped in gas hydrate.

The conditions of pressure and temperature required for gas hydrate to form are mostly present offshore in sediments of marine continental margins and onshore within and beneath continuous permafrost (permanently frozen ground). As gas hydrate forms, the hydrate structure can concentrate methane by up to 180 times compared to its volume as a free gas at air temperature and Earth's surface pressure conditions. This property means that methane hydrate represents a concentrated, shallowly buried form of natural gas that could be used as an energy resource or that could be perturbed by changing ocean or atmospheric conditions.

Contemporary estimates of mobile carbon trapped in natural gas hydrates vary by a factor of 10. In absolute amounts, global gas hydrate deposits are estimated to sequester 3–24.8 × 10^{15} cubic meters (106,000–876,000 trillion cubic feet or TCF) of methane (Boswell and Collett, 2011). For comparison, consumption of natural gas in the United States in 2016 exceeded 27.49 TCF according to the U.S. Energy Information Administration. Studies indicate that gas hydrates may prevent at least 10–15 percent of the global carbon inventory from circulating in the ocean-atmosphere system (Ruppel and Kessler, 2017).

The challenges inherent in studying gas hydrates explain why these compounds are not better characterized. For example, gas hydrates often occupy only a small fraction of the available space between sediment grains and will break down (dissociate) rapidly once removed from their original pressure and temperature conditions.

Energy Resources

The USGS Gas Hydrates Project provides leadership and expertise for the United States and for international programs that investigate the potential of gas hydrates as an energy resource. Project scientists have led, advised, or participated in more than a dozen domestic and international drilling projects to investigate the characteristics of gas hydrates in deepwater marine or Arctic permafrost settings (fig. 2). The participation of the USGS in the planning and execution of research projects on the Alaskan North Slope, in the Canadian Mackenzie Delta and the northern Gulf of Mexico, and offshore India, South Korea, and the northern Cascadia margins has contributed to substantial advances in understanding the geologic controls on gas hydrate distribution and the feasibility of extracting gas from these deposits.

The USGS uses a petroleum systems framework to evaluate sedimentary basins that may contain high-concentration gas hydrate deposits and often analyzes existing seismic and borehole logging data to infer where gas hydrate is concentrated (Collett and others, 2009). The USGS also collaborates with the U.S. Department of Energy and other Federal and State agencies, international partners, and private industry to plan drilling of research wells to recover samples of gas hydrates and to study gas production from hydrates. Such tests can improve information about the potential viability of gas hydrates as an economic source of natural gas.

Another important component of the USGS Gas Hydrates Project's energy studies is formal quantitative resource assessment. In 2008, the USGS completed the first-ever assessment of methane that is recoverable from gas hydrates by using existing technology. The case study focused on permafrost-associated gas hydrates on the Alaskan North Slope (U.S. Alaska Gas Hydrate Assessment Team, 2013) and adopted methodology that can be extended to other gas hydrate provinces. The USGS also frequently provides scientific and technical expertise to advance onshore and offshore gas hydrate assessments carried out by Federal and international collaborators.

Gas Hydrate and the Environment

The USGS Gas Hydrates Project is an international leader in examining the interaction of gas hydrate and the environment.

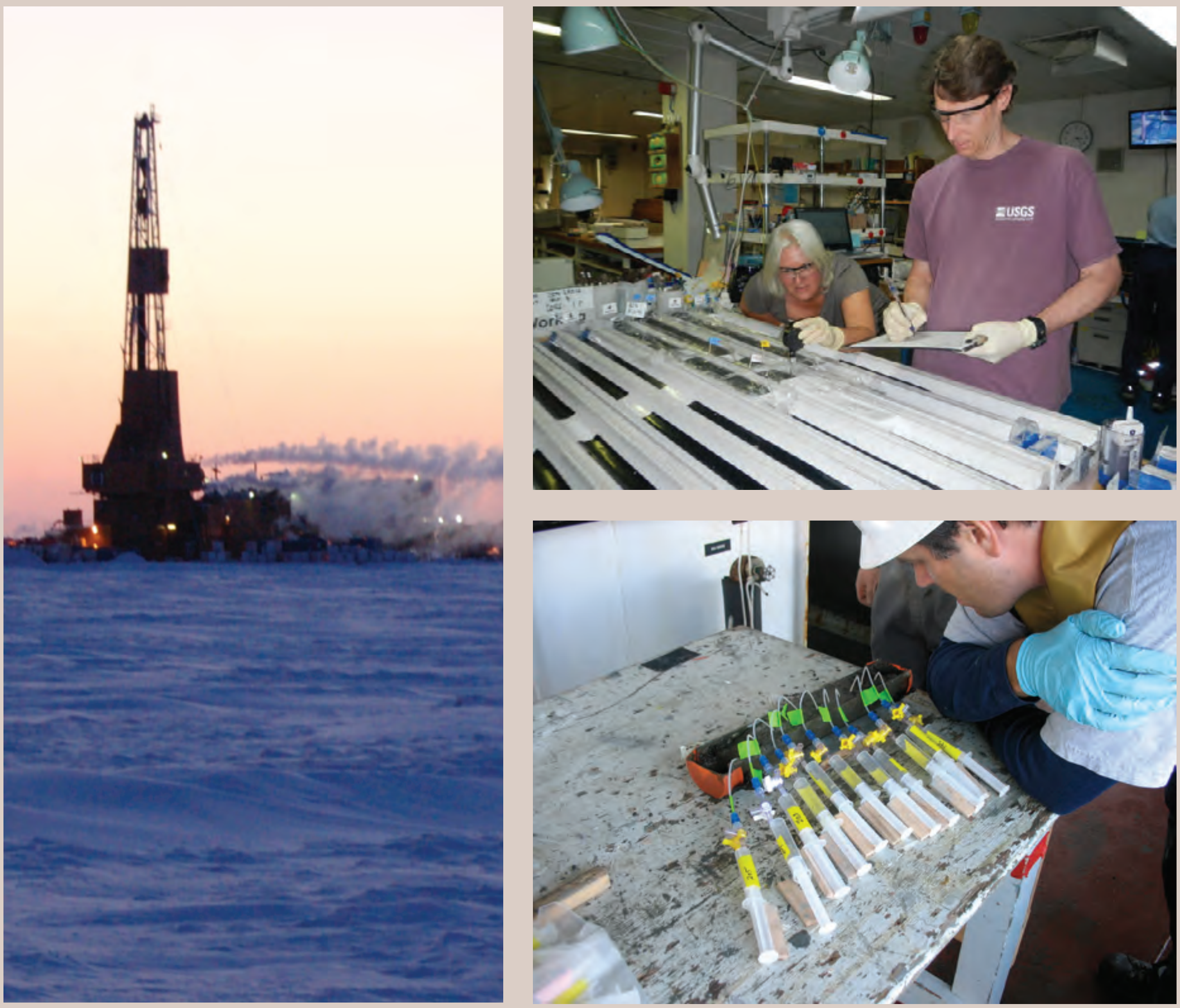

Figure 2. *A*, The drilling rig used to explore gas hydrates associated with onshore permafrost near Prudhoe Bay, Alaska, in 2007. *B*, U.S. Geological Survey scientists measuring the properties of sediment cores retrieved during a drilling expedition to investigate the energy resource potential of gas hydrates. *C*, During a 2008 coring expedition on the Vancouver margin, pore waters were extracted from sediments for later chemical analyses to determine the source of the methane.

Warm oceanic or atmospheric temperatures may destabilize gas hydrate deposits, which may then release methane to surrounding sediments and possibly to the ocean or atmosphere (fig. 3). As a potent greenhouse gas, methane that reaches the atmosphere could enhance climate warming. In the oceans, most of the methane emitted at the sea floor from degrading gas hydrates or other sources dissolves in the overlying waters, and some of the methane is converted to carbon dioxide by bacteria. Very little of the methane reaches the atmosphere if it is emitted at water depths of more than several hundred feet (Ruppel and Kessler, 2017). There are two settings in which gas hydrate is most susceptible to breaking down as oceans warm: one is on upper continental slopes at water depths of 300–800 meters (approximately 1,000–2,600 feet) and the other is on continental shelves that ring the Arctic Ocean and are underlain by permafrost (approximate water depth as much as 100 meters or 330 feet).

The USGS has developed regional maps of subsea permafrost distribution, which largely determines where gas hydrate that might be susceptible to warming ocean waters persists beneath the United States segment of the Arctic Ocean continental shelf. The USGS has also carried out oceanographic expeditions to map the distribution of gas hydrates beneath the upper continental slope in this part of the Arctic Ocean, to measure methane flux to the atmosphere at high latitudes, and to determine the rate of bacterial consumption of methane in the water column.

The USGS is also examining the susceptibility of gas hydrates to warming ocean waters on midlatitude upper continental slopes on the United States Atlantic margin, where the USGS played a role in discovering hundreds of previously unknown sea-floor methane seeps from 2012 to 2014 (Skarke and others, 2014). In cooperation with the U.S. Department of Energy, the National Oceanic and Atmospheric Administration, and other partners, the USGS is conducting oceanographic cruises to map the extent of gas hydrates; locate methane plumes in the water column; and obtain sea-floor samples for geological, geochemical, and biological analyses. In addition, scientists from the British Geological Survey and the USGS are collaborating to link the timing of methane emissions to climate change events.

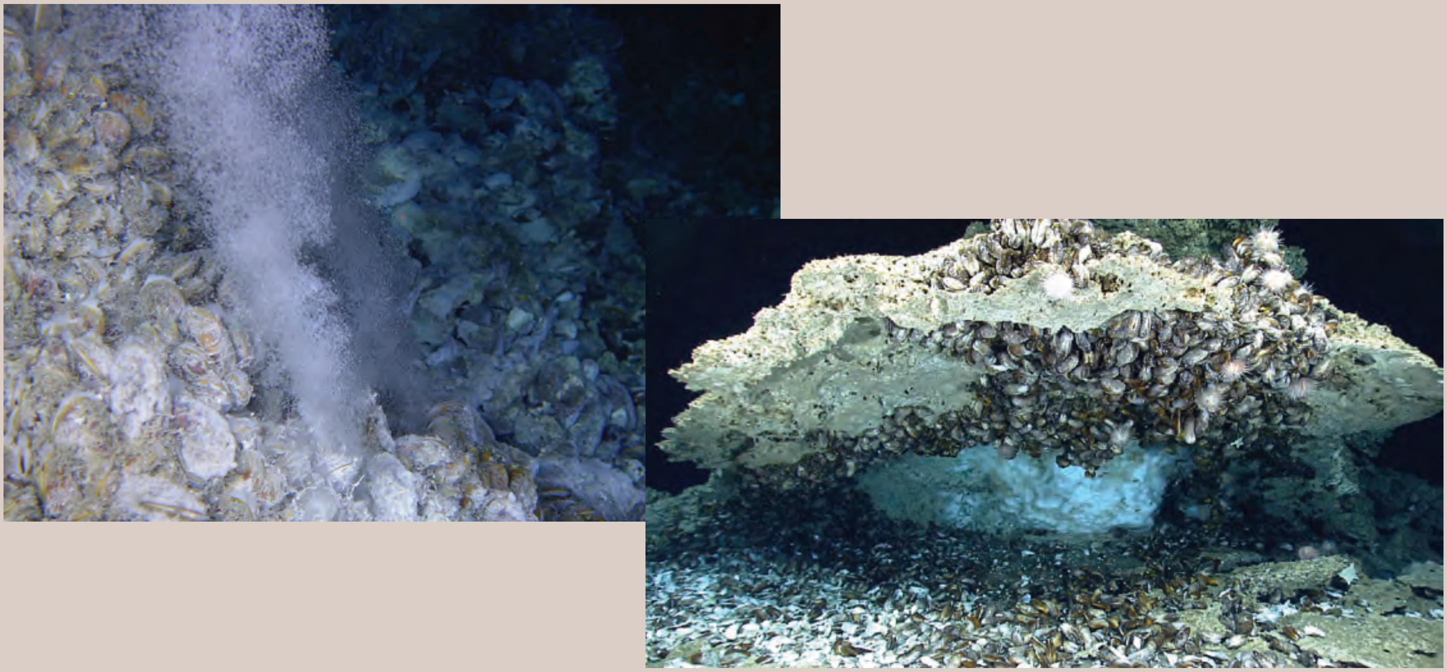

Figure 3. *A*, Methane seeping from the sea floor among deep-sea chemosynthetic mussels offshore Virginia at approximately 1,000 meters water depth (3,300 feet). Image acquired by the Global Explorer remotely operated vehicle managed by Oceaneering, Inc. *B*, Ice-like gas hydrates under capping rock encrusted with mussels on the sea floor of the northern Gulf of Mexico. Image taken by a remotely operated vehicle managed by the National Oceanic and Atmospheric Administration's Ocean Exploration and Research program.

Sea-Floor Stability

Submarine slides are unlikely to be caused by processes directly related to the formation of gas hydrates or the migration of free gas, but the presence of hydrates or gas bubbles in sediments may precondition slopes for failure during earthquakes. USGS researchers were among the first to recognize the spatial association of gas hydrate and submarine slides (Kayen and Lee, 1991), which can lead to tsunami and disrupt sea-floor infrastructure (for example, pipelines). Marine surveys conducted by the USGS have provided dramatic images of submarine slide scarps on United States marine margins and revealed the underlying distributions of free gas and gas hydrates. The USGS Gas Hydrates Project also measures the mechanical properties of hydrate-bearing and gas-charged sediments in the laboratory to use in models of submarine slope failure. Laboratory scientists also focus on the volume changes that accompany the breakdown of gas hydrates, an important issue for understanding sea-floor subsidence near conventional wells that are drilled through hydrate-bearing sediments or near future wells designed to extract methane from gas hydrates.

Laboratory Programs

The USGS Gas Hydrates Project maintains unique laboratory and field instrumentation for analyses of hydrate-bearing sediments, organic carbon, and methane. A scanning electron microscope with low-temperature capability allows researchers to image the arrangement of individual hydrate crystals and sediment grains, as shown in figure 4*A*. The USGS also operates a laboratory with state-of-the-art tools for measuring the properties of hydrate-bearing specimens maintained at their original pressure throughout the process of recovery from their natural setting, subsequent storage, and analysis (fig. 4*B*). The resulting data, as well as benchtop tests of methane production from dissociating gas hydrates, help scientists determine reservoir properties and the energy potential of gas hydrates. The USGS has also developed special geochemical tools to study components of the carbon cycle. These tools measure the properties of organic carbon in water-column and sediment samples and allow scientists to continuously determine the concentrations of methane and carbon dioxide in surface waters and the atmosphere during shipboard surveys.

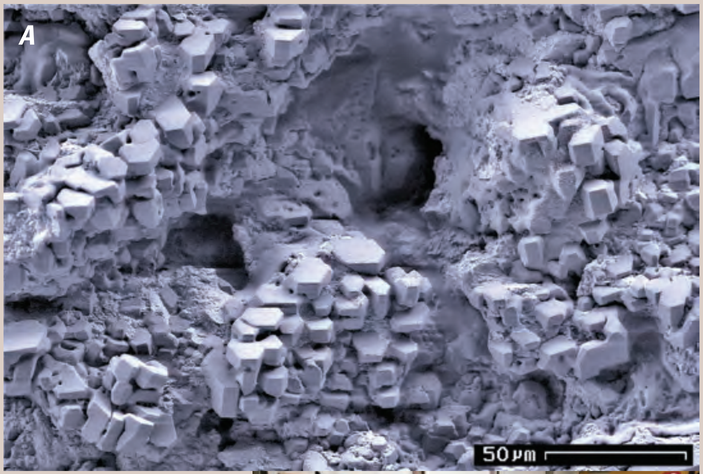

Figure 4. *A*, Scanning electron microscope image of gas hydrate crystals in a sediment sample. The scale is 50 micrometers (µm) or approximately 0.002 inches. *B*. USGS scientists work with special instrumentation for measuring the reservoir properties of hydrate-bearing sediments that are held at high pressures.

References Cited

Boswell, R., and Collett, T.S., 2011, Current perspectives on gas hydrate resources: Energy & Environmental Science, v. 4, p. 1206–1215, [Also available at https://doi.org/10.1039/C0EE00203H].

Collett, T.S., Johnson, A.H., Knapp, C.C., and Boswell, R., 2009, Natural gas hydrates—A review, *in* Natural gas hydrates—Energy resource potential and associated geologic hazards, ed. Collett, T.S., Johnson, A.H., Knapp, C.C., and Boswell, R.: American Association of Petroleum Geologists Memoir 89, p. 146–219.

Kayen, R.E., and Lee, H.J., 1991, Pleistocene slope instability of gas hydrate-laden sediment on the Beaufort sea margin: Marine Geotechnology, v. 10, no. 1–2, p. 125–141.

Ruppel, C.D., and Kessler, J.D., 2017, The interaction of climate change and methane hydrates: Reviews of Geophysics, v. 55, no. 1, p. 126–168. [Also available at https://doi.org/10.1002/2016RG000534].

Skarke, A., Ruppel, C., Kodis, M., Brothers, D., and Lobecker, E., 2014, Widespread methane leakage from the sea floor on the northern US Atlantic margin, Nature Geoscience, v. 7, no. 9, p. 657–661. [Also available at https://doi.org/10.1038/ngeo2232].

U.S. Geological Survey Alaska Gas Hydrate Assessment Team, 2013, National Assessment of Oil and Gas Project—Geologic assessment of undiscovered gas hydrate resources on the North Slope, Alaska: U.S. Geological Survey Digital Data Series 69–CC, 100 p. [Also available at https://doi.org/10.3133/ds69CC.]

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The USGS Gas Hydrates Project is supported by the USGS Coastal and Marine Geology Program and the USGS Energy Resources Program.

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- Overview of the U.S. Geological Survey's Gas Hydrates Project: https://woodshole.er.usgs.gov/project-pages/hydrates/index.html
- U.S. Geological Survey's Energy Resources Program gas hydrates site: https://energy.usgs.gov/OilGas/UnconventionalOilGas/GasHydrates.aspx
- Gas Hydrate in Nature, USGS Fact Sheet 3080: https://doi.org/10.3133/fs20173080

ISSN 2327-6916 (print)
ISSN 2327-6932 (online)
https://doi.org/10.3133/fs20173079