When Seafloor Meets Ocean, the Chemistry Is Amazing

In more and more places, scientists are finding vast amounts of natural gas on the ocean bottom

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Far more natural gas is sequestered on the seafloor—or leaking from it—than can be drilled from all the existing wells on Earth. The ocean floor is teeming with methane, the same gas that fuels our homes and our economy.

In more and more locations throughout the world's oceans, scientists are finding methane percolating through the seafloor, bubbling into the water column, collecting in pockets beneath seafloor sediments, or solidifying in a peculiar icelike substance, called methane hydrate, in the cold, pressurized depths of the ocean.

Massive deposits of methane hydrates could prove to be abundant reservoirs of fuel. But in the past, these massive storehouses of methane also may have "thawed" suddenly and catastrophically, releasing great quantities of climate-altering greenhouse gas back into the atmosphere.

In some places, seeping methane sustains thriving communities of exotic organisms that harness the gas as an energy source in their sunless environment. Below the seafloor, an unknown but potentially vast biosphere of microbes

A BUBBLING, LIFE-SUSTAINING BREW—Evidence is steadily growing that methane seeping and bubbling from the seafloor is a widespread, but previously overlooked, natural phenomenon. It can sustain communities of seafloor life, like these mussels in the Gulf of Mexico.

Earth-Ocean

FUEL FROM THE DEPTHS?—Methane, the same natural gas that we use as fuel, solidifies in the cold, pressurized depths. It is encapsulated by frozen water to form an icelike substance called methane hydrate, which could prove to be an abundant source of energy in the future.

may be making the methane that percolates upward. (See "Is Life Thriving Deep Beneath the Seafloor?' page 72.)

Other places on the seafloor show evidence that pockets of gas trapped beneath sediments have exploded to form "mud volcanoes," or may have triggered seafloor avalanches and tsunami waves.

An underestimated phenomenon

Until recently, scientists have largely overlooked seafloor methane and its potentially dramatic impacts. The problem is that methane commonly vents out of isolated cracks in the seafloor—some so small that they are easily missed by oceanic surveillance systems. Once out into the ocean, the methane usually is diluted rapidly by seawater, or it dissolves in seawater and is consumed by microorganisms that convert it metabolically into carbon dioxide. Unless you happen to be looking in the right place at the right time, you'll miss the show.

But evidence has steadily accumulated that natural seepage of methane from the seafloor is a large, continuous, and ubiquitous phenomenon. When oceanographers happen upon these vents (often called "cold seeps"), the scene is often spectacular.

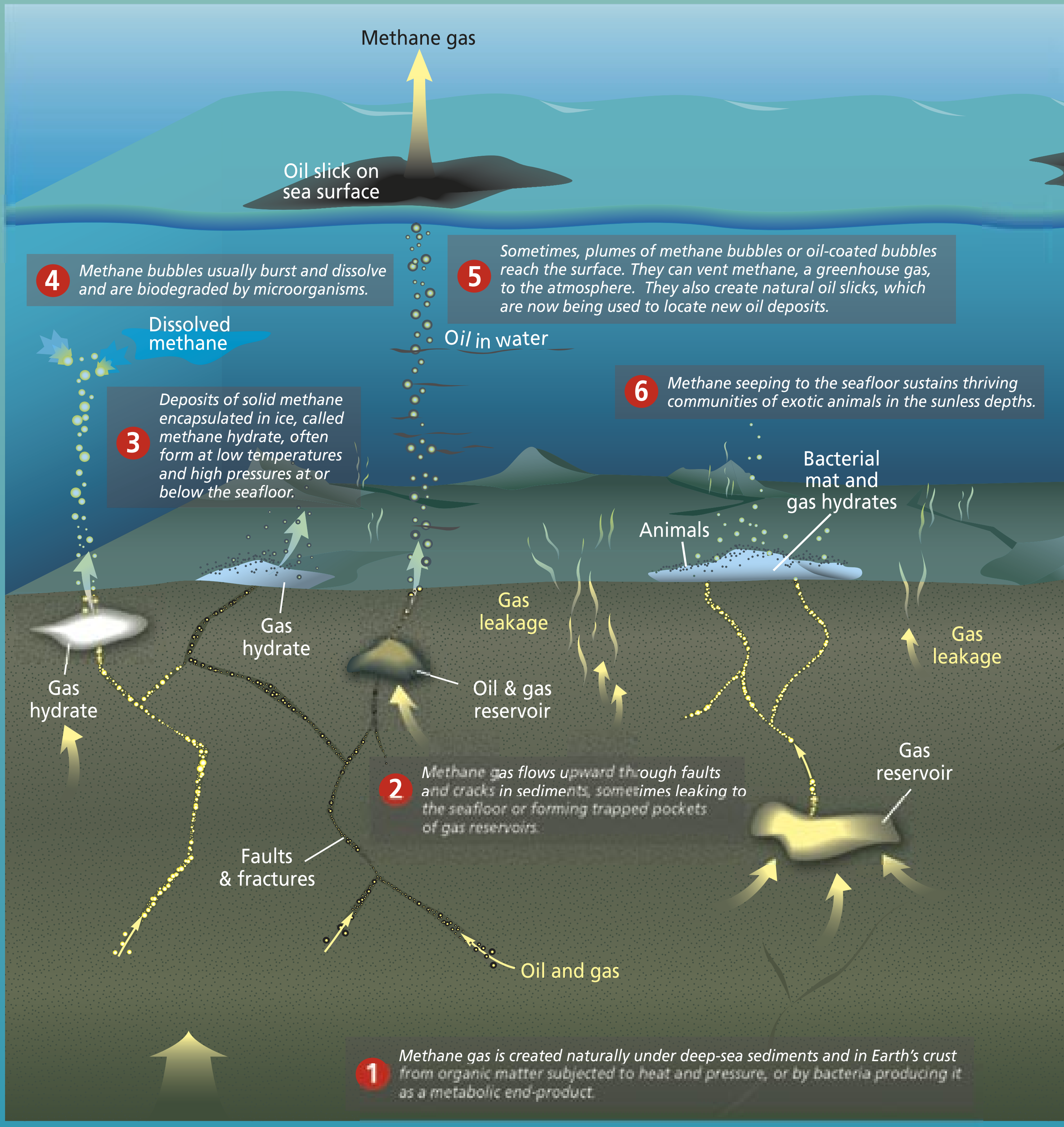
Several researchers have documented large craters or pockmarks on the seafloor, while others have described huge carbonate mounds (formed by organisms that ingest methane and produce carbonate). Both are often relics of past seafloor gas venting. Sometimes gas simply seeps from the ocean floor and sustains communities of unusual tubeworms, mussels, and other creatures like those found at hydrothermal vents. (See "The Evolutionary Puzzle of Seafloor Life," page 78.)

Gas frozen solid at the seafloor

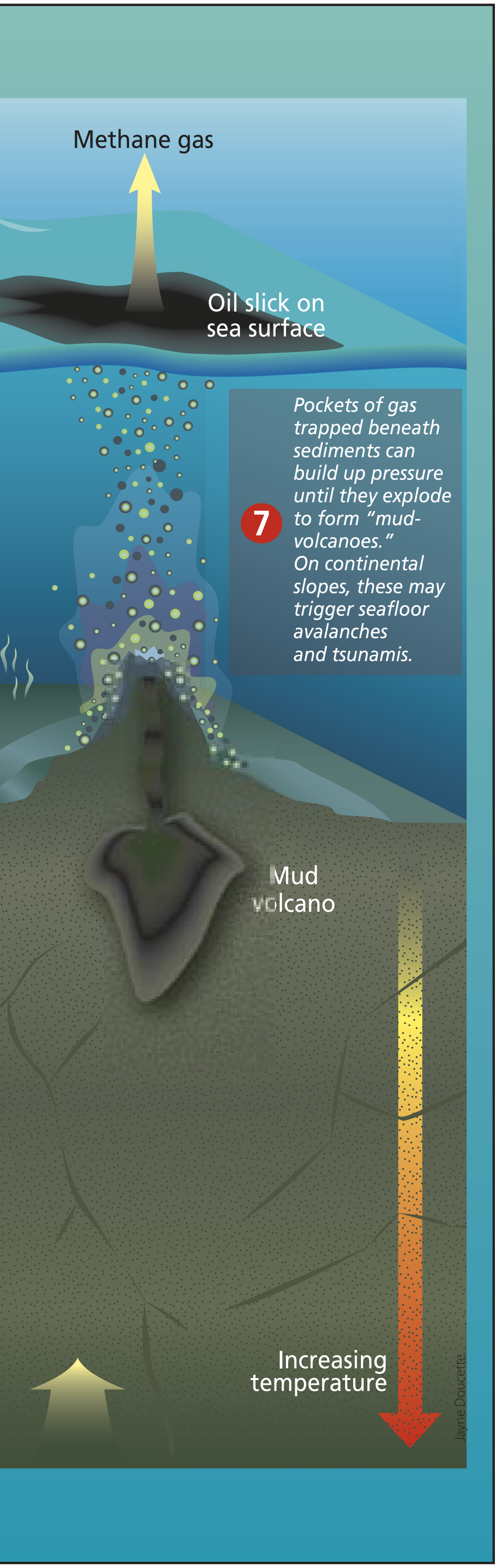
The deep ocean floor around gas seep sites is often covered by methane hydrates. These are solid crystals of methane encapsulated in ice, which form under the low temperatures and high pressures typical of ocean depths greater than about 1,500 feet.

These hydrates look like seafloor car-

The seafloor is teeming with methane



Scientists are discovering that abundant quantities of methane gas are continually seeping from the seafloor throughout the oceans. This wide-spread but overlooked natural phenomenon has potentially dramatic implications on world energy supplies, life in the oceans, and Earth's climate.



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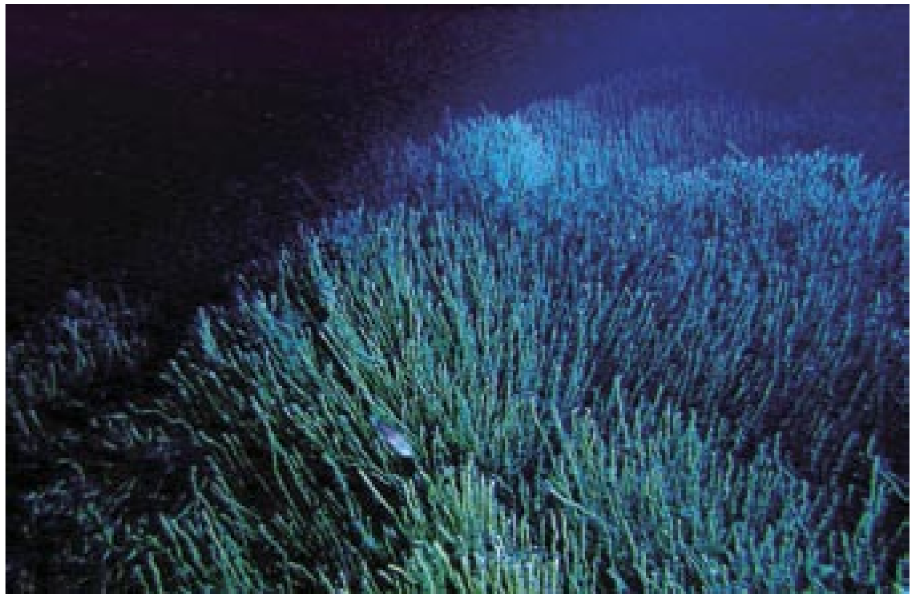


FED BY METHANE, LIFE FLOURISHES—Methane seeping from the seafloor sustains microbes that serve as the base of the food chain for communities of animals, like these tubeworms, which thrive in the sunless depths in the Gulf of Mexico.

bonate, but when chunks are broken off, methane hydrates float upward (carbonates sink). As those hydrates rise into higher temperatures and lower pressures, they decompose, releasing methane gas into the ocean—a process akin to releasing the pressure on a bottle of soda.

Energy companies have been eyeing methane hydrates as a potentially tremendous new source of natural gas. Since the 1930s, the use of natural gas has increased fivefold to account for more than 25 percent of the world's energy consumption. With existing technology, the world gas supply is estimated to be 5,300 trillion cubic feet (tcf), Robert Kleinberg of Schlumberger and Peter Brewer of Monterey Bay Aquarium Research Institute reported in *American Scientist*. At the current rate of global consumption (about 85 tcf per year), a 60-year supply remains.

But the amount of gas at various locations around the world varies widely. Russia and the Persian Gulf each have about 1,700 tcf, while the total for North America is about 260 tcf. Japan and Europe import nearly all of their natural gas, while India and China have very small domestic reserves.

A potential new energy resource

The untapped well of methane hydrates holds the promise of energy independence for nations close to oceans or permafrost regions (where conditions and consistently cold temperatures also create methane hydrates). Offshore methane hydrates would provide the U.S. alone an estimated potential natural gas reserve of 300,000 tcf. Projections of hydrate gas reserves in the ocean south of Japan are 2,000 times that country's very small existing natural gas reserves, according to Kleinberg and Brewer.

Most of the world's gas hydrates are sequestered in the deep ocean, presenting great challenges for potential commercial production. Hydrates dissolve quickly when removed from the unique conditions on the ocean bottom, so researchers must figure out how to either stabilize them or produce and transfer fuel directly from the seafloor.

Many known deep-water deposits, such as the Blake-Bahamas Plateau off the Carolinas, are very diluted or spread across relatively thin layers over wide areas, making them very difficult to "mine" economically. And deep-sea hydrates are often associated with complex biological communities

*STANDING TALL—Dense colonies of tubeworms (*Lamellibrachia luymesi*) aggregate around a cold seep site in the Gulf of Mexico. They form the seafloor equivalent of hedges that provide habitat for many other invertebrates, such as mussels, crabs, shrimp, and snails.*

that would be disrupted or destroyed by gas extraction and production.

Recharged oil wells

Recent work by a number of laboratories suggests that free gas streaming through the seafloor or seafloor hydrate deposits may constitute yet another large oceanic methane source. On the northern continental slope of the Gulf of Mexico, for instance, a process known as "gas washing" fills subsurface petroleum reservoirs with natural gas that flows upward from even deeper reservoirs in the Earth's crust.

It has been estimated that less than 2 percent of generated oil and gas ever makes its way into commercial reservoirs. Of the residual oil, about half remains dispersed in the source rock and sediments.

The residual oil and organic matter in deeper sediments is subjected to more heating and natural processing and is broken down into natural gas. The gas streams upward, washing out clogged pore spaces and recharging many fuel reservoirs. Evidence comes from oil wells in the northern Gulf of Mexico, where we have observed significant changes in oil compositions over time scales as short as 10 years. The wells continue to produce long after their expected lifetimes.

The other half of the residual oil leaks upward and out of the sediments into ocean bottom waters. Remarkable satellite photographs of the Gulf of Mexico and other regions reveal slicks extending for miles in areas where no oil production is occurring. Similar photographs are now being used to locate new oil and gas accumulations.

Methane-making microbes

Beyond the geological "cooking and squeezing" processes that produce petroleum and gas, large quantities of gas also are being produced biologically. Many gas hydrate accumulations and ocean-floor gas seeps consist of methane largely derived from microorganisms.

Bacteria living in oxygen-poor areas beneath deep-sea sediments on the seafloor produce methane as a major product of their metabolism. Some models suggest that bacteria in sediments may account for 10 percent of the living biomass on Earth. In addition, microbial communities beneath the seafloor, whose numbers are entirely unknown, may also be producing vast amounts of methane.

Global warming and tsunamis

The pervasive and ongoing movement of methane gas—from seeps, decomposing hydrates, gas washing, and microbial sources—leads to some fascinating phenomena and important questions.

Methane is a greenhouse gas that traps heat about 20 times more effectively than carbon dioxide. If methane deposits and seeps prove to be ubiquitous in the oceans, they are a potentially significant contributor to global warming.

Relatively modest changes in global

PLUMES UNFURLED—Like flower petals atop stems, feather-like red plumes poke out of the tops of the tubeworms' thin, white tubes, which reach about 50 centimeters (20 inches) high. The plumes act like gills, absorbing nutrients from seawater.

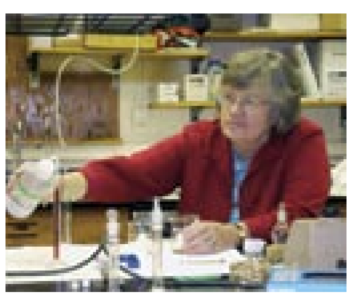
ocean temperatures or sea level could trigger a massive release of oceanic methane. If a change in ocean bottom pressure or a rise in water temperatures passes a certain threshold, sizable methane hydrate deposits could decompose rapidly and release a large quantity of heat-trapping gas back into the atmosphere. This scenario has been proposed as a possible cause for some past episodes of rapid global warming.

Evidence from the past suggests that upward-seeping methane may pose another threat: underwater avalanches. Landslides at the edge of the continental slope just off the East Coast of the United States may have been triggered by pockets of methane gas that had built up pressure under a lid of overlying sediments and exploded. Similar landslides today might generate tsunamis that would hit the U.S. coast. An offshore oil-drilling platform that accidentally hit such a gas pocket would also be endangered.

A wide-open new field

Many challenges remain ahead for researchers. Methane seeps are widely distributed around the world's oceans, yet their discovery remains mainly serendipitous. The volume of oil and gas seeping to the floor throughout the world's oceans is also unknown, as most of the seafloor remains unexplored.

Even in the cases of known seeps—especially those found in and around known oil and gas fields—data on the rates of seepage are scarce. Yet evidence suggests that gas seeps and methane hydrate deposits may be even more pervasive than their known extent today and may play a fundamental role in regulating ocean chemistry, sustaining marine life, and shaping seafloor geology.



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Jean Whelan earned her bachelor's degree in chemistry at the University of California, Davis, and her doctorate in organic chemistry from the Massachusetts Institute of Technology. Before coming to WHOI, she carried out postdoctoral work at Brandeis University and taught chemistry at Fairleigh Dickinson University in Madison, N.J. She studies how to use organic compounds to deduce geological processes. Among her research focuses are the formation and migration of petroleum, and she and colleagues have shown that large quantities of gas flowing through some of the world's oil and gas fields may be continuously altered and sometimes refreshed by pools of hydrocarbons that lie deep within the Earth. Current research focuses on how this gas seeping also affects the ocean. When she is not in her lab (or sometimes when she is), she loves to sing. A contralto, she has sung both as a choir member and a soloist with many Cape Cod choruses and chamber groups. as well as with her church choir.