

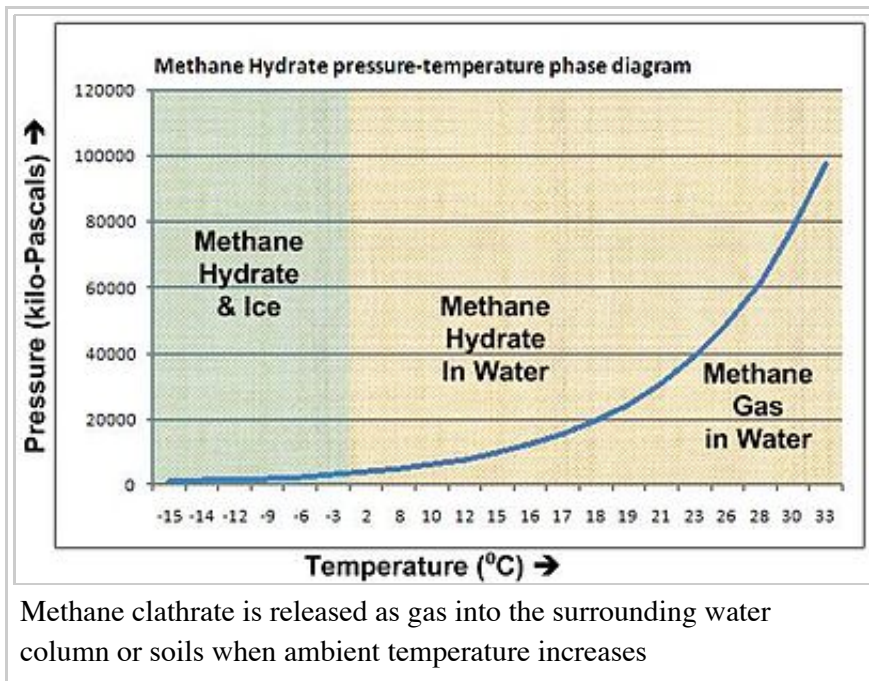
Clathrate gun hypothesis

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The **clathrate gun hypothesis** is the popular name given to the hypothesis that increases in sea temperatures (and/or falls in sea level) can trigger the sudden release of methane from methane clathrate compounds buried in seabeds and that contained within seabed permafrost which, because the methane itself is a powerful greenhouse gas, leads to further temperature rise and further methane clathrate destabilization – in effect initiating a runaway process as irreversible, once started, as the firing of a gun.^[1]

In its original form, the hypothesis proposed that the "clathrate gun" could cause abrupt runaway warming on a timescale less than a human lifetime,^[1] and was responsible for warming events in and at the end of the last glacial maximum.^[2] This is now thought to be unlikely.^{[3][4]}

However, there is stronger evidence that runaway methane clathrate breakdown may have caused drastic alteration of the ocean environment (such as ocean acidification and ocean stratification) and of the atmosphere of earth on a number of occasions in the past, over timescales of tens of thousands of years. These events include the Paleocene–Eocene Thermal Maximum 56 million years ago, and most notably the Permian–Triassic extinction event, when up to 96% of all marine species became extinct, 252 million years ago.^[5]



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Mechanism

Methane clathrate, also known commonly as methane hydrate, is a form of water ice that contains a large amount of methane within its crystal structure. Potentially large deposits of methane clathrate have been found under sediments on the ocean floors of the Earth, although the estimates of total resource size given by various experts differ by many orders of magnitude, leaving doubt as to the size of methane clathrate deposits (particularly in the viability of extracting them as a fuel resource). Indeed cores of greater than 10 cm contiguous depth had only been found in 3 sites as of 2000, and some resource reserve size estimates for specific deposits/locations have been based primarily on seismology.^{[6][7]}

The sudden release of large amounts of natural gas from methane clathrate deposits in runaway climate change could be a cause of past, future, and present climate changes. The release of this trapped methane is a potential major outcome of a rise in temperature; some have suggested that this was a main factor in the global warming of 6 °C that

happened during the end-Permian extinction,^[8] as methane is much more powerful as a greenhouse gas than carbon dioxide. Despite its atmospheric lifetime of around 12 years, it has a global warming potential of 72 over 20 years, 25 over 100 years, and 33 when accounted for aerosol interactions.^[9] The theory also predicts this will greatly affect available oxygen and hydroxyl radical content of the atmosphere.

Subsea permafrost



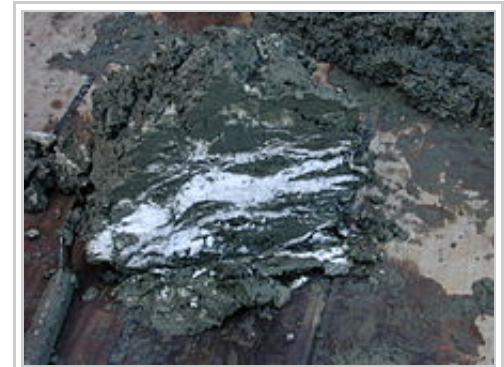
Specific structure of a gas hydrate piece, from the subduction zone off Oregon

Subsea permafrost occurs beneath the seabed and exists in the continental shelves of the polar regions.^[10] This source of methane is different from methane clathrates, but contributes to the overall outcome and feedbacks.

From sonar measurements in recent years researchers quantified the density of bubbles emanating from subsea permafrost into the ocean (a process called ebullition), and found that 100–630 mg methane per square meter is emitted daily along the East Siberian Shelf, into the water column. They also found that during storms, when wind accelerates air-sea gas exchange, methane levels in the water column drop dramatically. Observations suggest that methane release from seabed permafrost will progress slowly, rather than abruptly. However, Arctic cyclones, fueled by global warming, and further accumulation of greenhouse gases in the atmosphere could contribute to more rapid methane release from this source.^[11]

Metastable methane clathrates

Another kind of exception is in clathrates associated with the Arctic ocean, where clathrates can exist in shallower water stabilized by lower temperatures rather than higher pressures; these may potentially be marginally stable much closer to the surface of the sea-bed, stabilized by a frozen 'lid' of permafrost preventing methane escape.



Gas hydrate-bearing sediment, from the subduction zone off Oregon

The so-called self-preservation phenomenon has been intensively studied by Russian geologists starting in the late 1980s.^[12] This metastable clathrate state can be a basis for release events of methane excursions, such as during the interval of the last glacial maximum.^[13] A study from 2010 concluded with the possibility for a trigger of abrupt climate warming based on metastable methane clathrates in the East Siberian Arctic Shelf (ESAS) region.^[14]

Ocean anoxia

Anoxic and euxinic events happened in the past on different time scales ranging from decades to centuries (from impact events) or through climate change within tens of thousands of years or a few million years. According to Gregory Ryskin, such a scenario could lead to the release of methane and other gases (e.g., CO₂, H₂S) into the atmosphere, from the ocean. Following atmospheric methane excursions he postulates explosions and burning of methane would produce lots of smoke and dust, which would first lead to global cooling.^[15] And likely after a relatively short geological period following stratospheric cooling, global warming would take over.

Possible release events

Two events possibly linked to methane excursions are the Permian–Triassic extinction event and the Paleocene–Eocene Thermal Maximum (PETM). Equatorial permafrost methane clathrate may have had a role in the sudden warm-up of "Snowball Earth", 630 million years ago.^[16] However, warming at the end of the last ice age is not thought to be due to methane release.

Current outlook

Most deposits of methane clathrate are in sediments too deep to respond rapidly, and modelling by Archer (2007) suggests the methane forcing should remain a minor component of the overall greenhouse effect.^[17] Clathrate deposits destabilize from the deepest part of their stability zone, which is typically hundreds of metres below the seabed. A sustained increase in sea temperature will warm its way through the sediment eventually, and cause the shallowest, most marginal clathrate to start to break down; but it will typically take on the order of a thousand years or more for the temperature signal to get through.^[17] However, there is also a possibility for the formation of gas migration pathways within fault zones in the East Siberian Arctic Shelf, through the process of talik formation, or pingo-like features.^{[18][19][20]}

According to data released by the EPA atmospheric methane (CH₄) concentrations (ppb) remained between 400–800ppb (between years 600,000 BC to 1900) and since 1900 have risen to levels between 1600–1800ppb.^[21]

Arctic Ocean

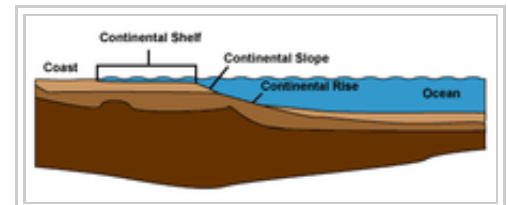
Research carried out in 2008 in the Siberian Arctic has shown millions of tons of methane being released, apparently through perforations in the seabed permafrost,^[20] with concentrations in some regions reaching up to 100 times normal levels.^{[22][23]} The excess methane has been detected in localized hotspots in the outfall of the Lena River and the border between the Laptev Sea and the East Siberian Sea. Some melting may be the result of geological heating, but more thawing is believed to be due to the greatly increased volumes of meltwater being discharged from the Siberian rivers flowing north.^[24] Current methane release has previously been estimated at 0.5 Mt per year.^[25] Shakhova et al. (2008) estimate that not less than 1,400 Gt of carbon is presently locked up as methane and methane hydrates under the Arctic submarine permafrost, and 5–10% of that area is subject to puncturing by open taliks. They conclude that "release of up to 50 Gt of predicted amount of hydrate storage [is] highly possible for abrupt release at any time". That would increase the methane content of the planet's atmosphere by a factor of twelve,^{[26][27]} equivalent in greenhouse effect to a doubling in the current level of CO₂.

In 2008 the United States Department of Energy National Laboratory system^[28] and the United States Geological Survey's Climate Change Science Program both identified potential clathrate destabilization in the Arctic as one of four most serious scenarios for abrupt climate change, which have been singled out for priority research. The USCCSP released a report in late December 2008 estimating the gravity of this risk.^[29] A 2012 assessment of the literature identifies methane hydrates on the Shelf of East Arctic Seas as a potential trigger.^[30]

Continental slopes

A trapped gas deposit on the continental slope off Canada in the Beaufort Sea, located in an area of small conical hills on the ocean floor is just 290 meters below sea level and considered the shallowest known deposit of methane hydrate.^[31]

Seismic observation of destabilizing methane hydrate along the continental slope of the eastern United States, following the intrusion of warmer ocean currents, suggests that underwater landslides could release methane. The estimated amount of methane hydrate in this slope is 2.5 gigatonnes (about 0.2% of the amount required to cause the PETM), and it is unclear if the methane could reach the atmosphere. However, the authors of the study caution: "It is unlikely that the western North Atlantic margin is the only area experiencing changing ocean currents; our estimate of 2.5 gigatonnes of destabilizing methane hydrate may therefore represent only a fraction of the methane hydrate currently destabilizing globally."^[32]



Profile illustrating the continental shelf, slope and rise

Model simulations

A study based on a coupled climate–carbon cycle model (GCM) assessed a 1000-fold (from <1 to 1000 ppmv) methane increase - within a single pulse, from methane hydrates (based on carbon amount estimates for the PETM, with ~2000 GtC), and concluded it would increase atmospheric temperatures above >6 °C within 80 years. Further, carbon stored in the land biosphere would decrease by >25%, suggesting a critical situation for ecosystems and farming, especially in the tropics.^[33]

In fiction

- The science fiction novel *Mother of Storms* by John Barnes offers a fictional example of catastrophic climate change caused by methane clathrate release.
- In *The Life Lottery* by Ian Irvine unprecedented seismic activity triggers a release of methane hydrate, reversing global cooling.
- The hypothesis is the basis of an experiment in the PlayStation 2 game *Death By Degrees*.
- In *Transcendent* by Stephen Baxter, averting such a crisis is a major plotline.
- The novel *The Black Silent* by author David Dun features this idea as a key scientific point.
- In the anime *Ergo Proxy*, a string of explosions in the methane hydrate reserves wipes out 85% of human life on Earth.
- The novel *The Far Shore of Time* by Frederik Pohl features an alien race attempting to destroy humanity by bombing the methane clathrate reserves, thus releasing the gas into the atmosphere.
- The novel *The Swarm* by Frank Schätzing features what first appear to be freak events related to the world's oceans.
- In Charles Stross' Laundry Files universe, an intentionally triggered clathrate gun scenario is viewed as a possible retaliatory strategy that could be utilized by Blue Hades in response to terminal violation of the Benthic Treaty.

See also

- Azolla event
- Clathrate compound
- Long-term effects of global warming
- Limnic eruption
- Mass extinction
- Methane chimney
- Ocean acidification
- Physical impacts of climate change
- Shutdown of thermohaline circulation
- Storegga Slide

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