TERRESTRIAL METHANE HYDRATE: A POTENTIALLY UNIVERSAL PLANETARY ATTRIBUTE. IS HYDRATE A KEY TO HUMAN HABITATION OF OTHER PLANETARY BODIES?

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Introduction: Terrestrial gas hydrates comprise ice-like crystalline compounds of gas (mainly methane) and water which are stable both at very low temperatures in permafrost regions, and in the low temperature - high pressure regimes present in the deep oceans on Earth [1]. Methane and other gases are thermodynamically stabilized within gas hydrates by hydrogen bonding in a crystalline lattice of water molecules [2]. Hydrate forms in both primary and secondary pore space and fractures in sediments as a diagenetic mineral. The presence of hydrate, which replaces water in pore space, strongly alters the physical properties of the sediments in which it occurs. Although hydrate is generally referred to as an 'ice-like' material and some of the physical properties of hydrate are similar to water-ice, they are different in some respects (Table 1).

Property	Ice	Hydrate
Dielectric constant at 273 °K	94	~58
NMR rigid lattice 2nd moment of H2O protons(G2)	32	33 ± 2
Water molecule reorientation time at 273 °K (µsec)	21	~10
Diffusional jump time of water molecules at 273 °K (µsec)	2.7	>200
Isothermal Young's modulus at 268 °K (109Pa)	9.5	~8.4
Pressure wave Velocity (km/sec)	3.8	~4
Transit time (µsec/ft)	3.3	92
Velocity ratio Vp/Vs (272 °K)	1.88	1.95
Poisson's ratio	0.33	~0.33
Bulk modulus (272 °K)	8.8	5.6
Shear modulus (272 °K)	3.9	2.4
Bulk density (gm/cm3)	0.916	0.912
Adiabatic bulk compressibility at 273 °K 10-11Pa	12	~14
Thermal conductivity at 273 °K (W/m-K)	2.25	0.50±0.02
Heat of fusion (kJ/mol)	6	54*, 57**

Table 1. Physical properties of water ice and methane hydrate [3]. * Measured, ** Calculated.

On Earth, hydrate concentrates methane produced in the deep biosphere by bacteriological decomposition of organic matter [4, 5], especially on passive continental margins where plunging plate boundaries and subduction zones are not present to provide pathways for deep-sourced thermogenic methane. Gaseous methane migrates upwards, and is concentrated within and immediately beneath a zone in which hydrate is thermodynamically stable. This is the Hydrate Stability Zone (HSZ), that extends downward from the cold seafloor in water depths greater than about 500 m water depth in non-Polar, open ocean conditions, and in permafrost regions from some depth within the water-ice permafrost zone (~200 m) to some depth that is determined locally by rising temperature.

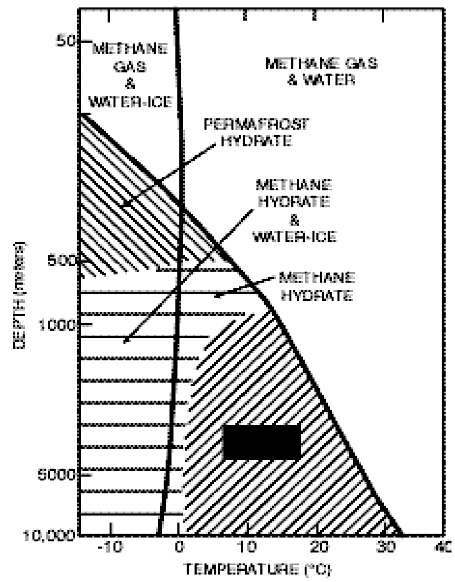

Figure 1. Earth P-T stability field of methane hydrate.

Methane hydrate occurs in two general environments on Earth; in a compound hydrate-cryosphere in permafrost regions and in oceans, mainly on upper and middle water depth continental slopes. Oceanic hydrate contains up to 95% of all naturally occurring hydrate worldwide. On cold planets such as Mars, however, where no deep oceans now occur, gas hydrate would be found entirely in the cryosphere and its analog on Earth is hydrate that is found in permafrost regions.

Permafrost hydrates exist at low pressures and temperatures (Fig. 1). On Earth they occur as part of a compound water-ice and hydrate permafrost on land and on continental shelves of Alaska, Canada, and Russia. Methane hydrate and water-ice form a compound cryogenic zone (Fig. 2). Water-ice is stable from the surface at about 0 °C whereas hydrate is stable from some depth below the surface (depending on average surface temperature, total pressure, and geothermal gradient) to some depth below the base of the water-ice stability zone. In Alaskan permafrost, local thermal variations result in maximum hydrate stability depths of 600 - 1075 m with associated crustal temperatures of ~285 - 287 K [6].

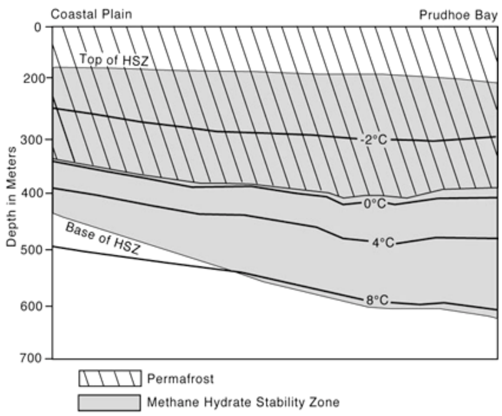

Figure 2. Cross-section of compound water ice – methane hydrate 'cryosphere'.

Methane may have been recovered from hydrates in Russia from permafrost-associated gas hydrates at the Messoyakha field in western Siberia for over 15 years. Recovery tests of methane from similar gas hydrates in the Prudhoe Bay field have yielded methane recovery rates similar to those in Russia and techniques of methane recovery from hydrate in the Alaskan and Canadian permafrost terrane are underway now with international participation [7].

At the 200 °K average surface temperature of Mars, hydrate is not stable at less than a depth of ~15 m (assuming an ice-saturated permafrost density of 2.5×10^3 kg m^{-3}). The base of the Martian HSZ should then extend to depths that lie from several hundred meters to as much as a kilometer below the base of the water-ice cryosphere. Thus, the total thickness of the Hydrate Stability Zone on Mars is likely to vary from ~3 km at the equator, to ~8 km at the poles [8].

Energy potential of natural gas hydrate: Hydrate formation forces methane molecules into closely-packed guest lattice sites, which has the effect of concentrating the methane. One cubic metre of naturally occurring methane hydrate contains ~164 m^3 of methane (at STP) and ~0.87 m^3 of pure water [1, 3] at an approximate ratio of methane and water [CH_4 • 6.1 (±0.1%) H_2O]. Although the essentially pure water in hydrate on Earth occurs in very large volumes, it is mainly the energy content of the methane hydrate that is of primary interest [1].

The amount of methane held in the form of gas hydrates on Earth is estimated to be at least 1×10^4 gigatons of carbon [2], or about twice as much as all known fossil-fuel deposits (coal, oil, and natural gas). Methane associated with the hydrates appears to represent an important potential energy resource. Methane hydrate has a high energy density (184,000 Btu/ft^3 compared with 152,000 BTU/ft^3 for liquid methane, and 1,150 BTU/ft^3 for methane gas at STP). The methane occurs both in the hydrate itself and in gas deposits associated with the hydrate-rich horizons.

Impact of widespread methane hydrate in the Solar System: Of primary importance, the raw products of dissociation of methane hydrate are virtually pure water and methane; the water of life and fuel. Methane can be used as a feedstock for producing higher energy density liquid fuels or used directly or as a source of pure hydrogen in fuel cells. Second, water, methane, and CO_2 can be used as primary industrial feedstock in a wider petrochemical industry wherein fabricated items can be manufactured.

Because the conditions for the formation of methane hydrate occur on several planets (Earth and Mars at least) and on water-rich bodies such as some of the moons of Jupiter, methane hydrate is likely to be found distributed widely in the solar system and beyond. Thus, a space exploration technology based on the concept of survivability exploiting the down-stream benefits of methane and other gas hydrates, which have concentrated substances vital to support human habitation away from Earth, may prove to be the key to early self-sufficient colonization of space.

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