METHANE HYDRATE EXPLORATION ON MARS: A TEST BED FOR DEVELOPMENT OF STRATEGIES FOR PLANETARY EXPLORATION

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NASA, along with its international partners, has developed a Mars exploration strategy, based on robotic missions, that extends well into the next decade. Because of its proximity to Earth, the abundant evidence for water, and the implications that water has for the development and persistence of life, Mars is also the next likely target for human exploration and colonization. As such, it will also serve as an important test bed for the development of techniques for deep biosphere exploration and resource evaluation for other bodies in the solar system.

If the early evolution of the Earth and Mars followed similar paths, then it's possible that methanogenic bacteria may have developed in the planet's early aqueous surface and near-surface environment (Max & Clifford, 2000). During the transition of the early Martian hydrosphere to the colder conditions that characterize the planet today, such early life may have adapted to subpermafrost conditions similar to the present deep biosphere environment of the Earth. The potential existence of such a deep microbial biosphere on Mars has enormous implications for the potential development of life, and the availability of methanogenicly-produced resources, elsewhere in the solar system (such as the putative deep mantle ocean of Europa).

On Mars, as on Earth, it is expected that biogenic methane will migrate upward in lithic pore water in deep crusts until it reaches the hydrate stability zone (HSZ), is the region defined by the temperature and pressure regime where methane hydrate is stable. Methane produced by organisms in subsurface sediments is often naturally concentrated by buoyant migration and confinement beneath low permeability strata and ice-sealed traps. On Mars, this potential is likely enhanced by the widespread occurrence of subsurface permafrost.

The methane trapped in these deposits may occur as both gas pockets or, under appropriate conditions of temperature and pressure, as a hydrate that takes the form of intergrown, poorly-defined ice-like crystals. Hydrocarbons (mostly methane), as well as other gases, are thermodynamically stabilized in gas hydrates by hydrogen bonding (Van der Waals weak electrical forces) within a cubic crystalline lattice of water molecules. Because not all the guest sites within the lattice are generally occupied, gas hydrates are non-stoichiometric compounds of methane and water [$CH_4 \cdot 6.1\ (\pm 0.1\%)\ H_2O$]. Hydrate formation concentrates methane by forcing the molecules into closely packed lattice sites in the hydrate crystals (at a molecular density that exceeds that of even liquified methane). Typically, 1 m^3 of naturally occurring 90% saturated methane hydrate contains 164 m^3 of methane gas (at STP) and 0.8 m^3 of liquid water (Kvenvolden, 1993).

The stability field of methane hydrate is constrained by the increase in crustal temperature and pressure that occurs with depth. On Earth, hydrate is found in the intergranular pore space of rocks and sediments at depths as shallow as 150-200 m in permafrost regions, and in the low-temperature, high-pressure conditions found on the deep ocean floor. Like permafrost, the maximum depth at which hydrate remains stable is limited by crustal temperature, although the pressure-temperature fields of water-ice and methane hydrate differ considerably (Fig. 2). The region of the crust that satisfies the thermodynamic stability criteria for methane hydrate is called the Hydrate Stability Zone (HSZ), whose thickness is governed by the magnitude of the local geothermal gradient (i.e., being greater for shallow gradients and thinner for steeper gradients).

In practice, determining the absolute depth to which methane hydrate will remain stable is complex because of dissolved solids and the local geothermal gradient, the mean annual surface temperature and the recent thermal history of the crust. Beneath this depth, methane persists as a gas. For example, large gaseous methane deposits associated with water below the HSZ have been identified off the southeastern coast of the United States (Fig. 1). The low acoustic velocity (Vp) gas beneath the sediment whose porosity has been filled to the extent that it reduces permeability and traps the gas beneath it (while increasing the seismic velocity of the hydrate-rich sediment, forms a strong negative impedance reflector called the Bottom Simulating Reflector (BSR). This stratification of methane hydrate within the HSZ and gaseous methane below, is characteristic of hydrate systems on Earth, with the occasional exception of gas pockets within the HSZ that have not reacted with water to form hydrate.

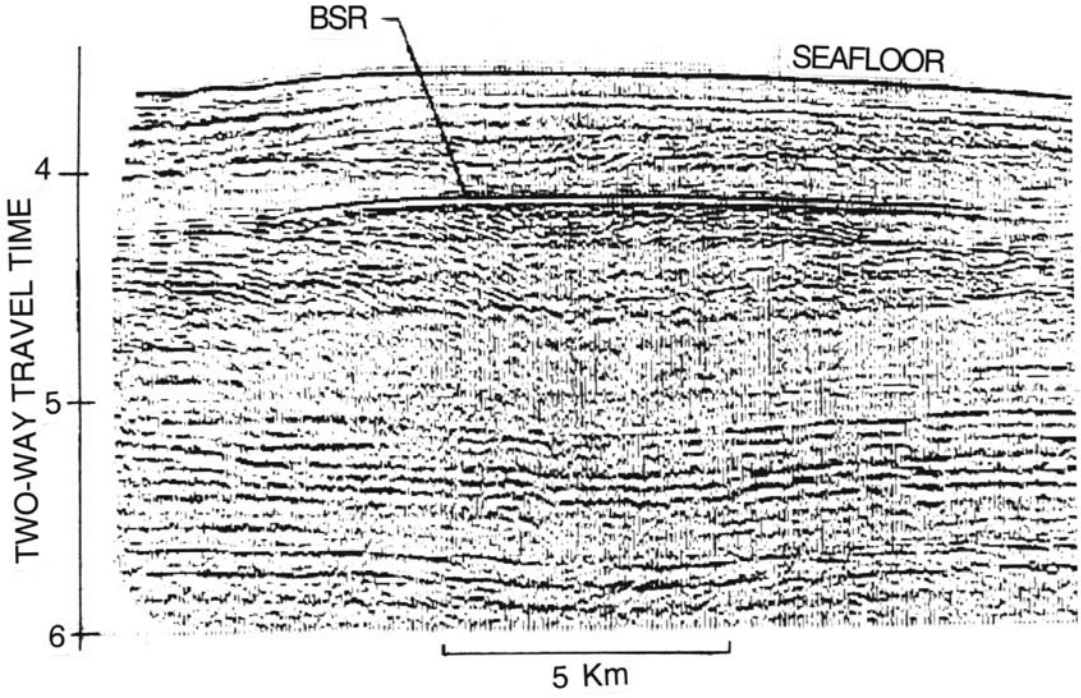

Figure 1. From Max, 1999. Original seismics from W.P. Dillon, U.S. Geological Survey

Methane hydrate and water-ice form a compound cryogenic zone. Water-ice is stable from the surface to about 0 °C and 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, variations in the local thermal properties of the crust can yield maximum hydrate stability depths of 600 - 1075 m with associated crustal temperatures of ~285 - 287 K.

On Mars, methane hydrate is stable close to, but not at, the surface. Since the dominant constituent of the crust appears to be basalt (or basalt-derived weathering products), the difference in lithostatic pressure at any depth between Mars and the Earth simply scales in proportion to the ratio of gravitational accelerations for the two planets (i.e., ~0.38 g). At the 200 K average surface temperature of Mars, hydrate is not stable at less than about 140 kPa, which corresponds to a depth of ~15 m (assuming an ice-saturated permafrost density of 2.5x103 kg m-3). Given a reasonable estimate of the thermal properties of the crust, 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. 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 HSZ (Max and Clifford, 2000).

Hydrate formed during the early phases of establishment of the Martian cryosphere, however, may still exist as 'perched' deposits near the surface of Mars, encased by water ice. If concentrated methane in the form of methane hydrate can be found in the near subsurface of Mars or otherwise easily accessible on other bodies in the solar system, then all the elements necessary for the human occupation may exist. Because hydrate compresses methane (and carbon dioxide hydrate), concentrated methane and carbon dioxide may exist in relatively rich deposits.

Methane deposits can be primarily considered as a fuel while the water produced from hydrate can be expected to be pure and potable with minimal processing. The possibility that fuel and pure water can be found collocated on Mars and other bodies in the solar system should cause a review of exploration strategies.

Identification of deep biosphere and gas (methane and carbon dioxide) hydrates on Mars, therefore, should be considered as a strategic priority for planetary research. Exploration techniques that are currently being used or developed to identify and quantify gas hydrate on Earth can be used on Mars. In the first instance, the primary means of detecting hydrate is seismic and acoustic analysis. This common geophysical method consists of using well located sound sources and geophones to produce a set of seismic data, which can be processed and interpreted to reveal detailed subsurface structure and material properties. Remotely operated seismic exploration techniques on the surface of Mars, combining modified geophysical industry equipment and procedures, marine science acoustic experimental equipment and procedures, and new processing and analysis techniques, can be used to identify hydrate and gas deposits.

In addition, remote autonomous drilling can penetrate into the subsurface, where the real search for deep biosphere must be conducted. Technology developed for autonomous drilling in the deep seafloor can be extrapolated to Mars.

Reference

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