

Methane Clathrate Behavior in Martian Surface Ice, and Supporting Morphological Observations.

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Introduction: Earlier, we reported on the likelihood that methane clathrate hydrate in martian glaciers and other surface ice is the source of ancient glacial meltwater features and modern atmospheric methane [1, 2, 3]. In the current work, we consider the behavior of methane clathrate in surface ice, and describe geomorphic features that we interpret as being related to clathrate dissociation. Methane clathrate may also be present in permafrost ice [4 5], but because sublimation of ice at the surface is inevitable, downward migration of the HSZ (Hydrate Stability Zone) must result in the gradual destabilization of any clathrate present in surface ice, without the need to hypothesize any other special conditions.

Behavior of clathrates in surface ice:

Clathrate viscosity and initial distribution. Just below the ice point, methane clathrate is more than 20x stronger than water ice, and the difference is greater at lower temperatures [6], so a hypothetical glacier made entirely of methane clathrate would have to undergo an unrealistic amount of strain before it would flow. Dissociation at the base of a thick, clathrate-rich glacier, where the temperature would be higher due to geothermal heating, could allow it to be wet-based, and it might move as a uniform slab. However, a uniform initial distribution is unlikely. Local and temporal variations in thermodynamic or chemical conditions would create layers or pockets that would be further broken up by any movement of the ice matrix between them [2]. In addition, if the methane in the clathrate is of microbial origin, its initial distribution depends on the growth of the microbes. Clathrate located in surface ice is more likely than permafrost clathrate to be of microbial origin because methane migrating from deep geological sources would cause clathrates formation at the bottom of the permafrost.

Clathrate deformation and eventual distribution. Inelastic deformation disrupts the clathrate structure and causes dissociation even where the clathrate is thermodynamically stable [6], thus breaking clathrate-rich layers into chunks. Methane clathrate has a density similar to water ice, so clathrate-rich chunks distributed throughout an otherwise relatively clathrate-free glacier should behave like low-density rocks, and have little effect on the overall viscosity or rate of flow of the ice as long as they remain stable. The eventual distribution of the clathrate will be a result of ice movement and thermodynamics [3].

If clathrate dissociates due to deformation in the HSZ, some methane may escape to the atmosphere. Trapped methane can re-combine with water to make clathrate again, but if methane does escape and the temperature is high enough, films and small pockets of water or brine can form [6]. In a glacier or debris flow with an ice matrix, this increases pore pressure and allows slippage of the surrounding layers of ice. When the ice regelates or the clathrate re-associates, slippage stops. If ruptures are on a large enough scale, the ice will move episodically, with most of the movement probably near the toe of the glacier or debris flow, where strain rates are highest. We surmise that this internal slippage will make the upper surface roll over the underlying layers, so that a glacial surface might even move at a higher average velocity than if the clathrate were not present. Movement of the ice would transport some clathrate “rocks” out of the HSZ.

Dissociation due to thermodynamics. In northern Arabia Terra and Deuteronilus, viscous flow features are common, though it is difficult to differentiate among debris flows, remnant glaciers [e.g. 7], and intermediates such as rock glaciers or ice-rich mudflows. Sublimation rates are also problematic because the amount and thickness of protective dust and debris is unknown, and varies with the age of the surface and other factors. As sublimation occurs, a dissociation front migrates downward, creating a Hydrate Destabilization Zone (HDZ), where thermodynamic conditions have recently deteriorated, but dissociation is incomplete. The bottom boundary of the HDZ is the upper surface of thermodynamic HSZ; the depth of upper boundary of the HDZ depends on the sublimation rate of the ice and the dissociation rate of the clathrate [3].

Downward migration of the HDZ creates plumes of methane escaping from within the ice. Plumes are transient because cracks and fissures through which the gas escapes will become blocked by regelation of the water released. The plumes elevate the local methane mixing ratio, and if the surrounding ice is warm enough, they may bring some liquid water to the surface at the same time. This water will be deposited near the vent, so that recent plumes may be evident as bright annular or starburst patterns. High pressure plumes, especially where conditions are cold enough to preclude escape of liquid water, may also bring dust or larger particles of sediment to the surface, creating dark patterns around vents, perhaps including the “spi-

ders” of the South Polar Layered Deposits (which may be from dissociating CO₂ clathrate).

Morphologic observations: In Arabia Terra, which has been identified as high in both water and atmospheric methane [8], we observe morphologies that are consistent with recent and ongoing gas release from dissociating clathrates.

Sheet avalanche. MOC NA E1100014 shows a mantled northwest facing slope of a tributary to Mamers Valles. At the foot of the mantle is a thin layer with transverse ridges superimposed on lineated valley fill (LVF). The transverse ridges resemble compressional ridges seen on terrestrial rock glaciers where they encounter an underlying break in slope [9]. Here, the underlying LVF is visible beneath the ridged layer, which suggests that the ridges are part of a thin layer superposed on a wider main flow. We interpret this feature as a layer of an icy hillslope mantle that detached and slid to the bottom of the slope, consistent with the presence of a dissociating layer of clathrate. A similar “crumpled” layer is seen in Fig. 1.

Rings. Near the mouth of Mamers Valles, lobate flows are common. At the edges of some of these lobate flows there are rings ~30-100 m across (Fig. 1-2), which we interpret as fluid escape structures, where methane and water erupted when clathrate dissociated. The bright tone of some of the rings may reflect their youth.



Figure 1: Detail of MOC NA r2300595, showing degraded mesa with debris apron, near the mouth of Mamers Valles. Note the ring-shaped features clustered on the smooth part of the debris apron, in the southeast. We interpret the bright rims on some of these features as ice deposition associated with the escape of methane from clathrate, not yet masked by eolian dust deposition. Also note the lineations that resemble a crumpled layer superimposed on the debris apron in the bottom left of the image; compare to MOC NA E1100014. North is at the top; image is ~2.77 km across

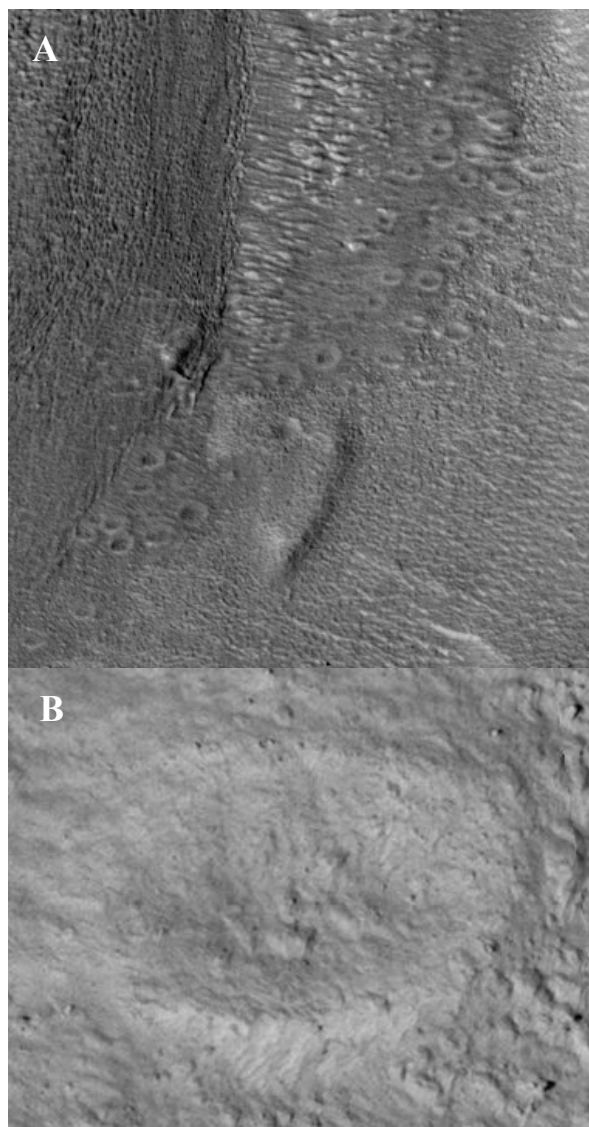


Figure 2: A. Detail of HiRISE PSP_001426_2200_RED, near 39.81N 23.07E, showing ring features associated with part of a viscous flow feature at the upper left. North is at the top; image is 1446 m across. B. Close-up of single ring feature.

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